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EFFECT OF A FLYASH CONDITIONING AGENT ON POWER PLANT EMISSIONS

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16. ABSTRACT

The report gives results of a study undertaken as a preliminary program to provide data on the environmental effects of a chemical flyash conditioning agent (Apollo Chemicals conditioner LPA 402A). Both the emissions due to the chemical and its effect on electrostatic precipitator (ESP) performance were investigated. The tests were conducted over a 10-day period at Pennsylvania Power and Light Co.'s Montour Plant with the plant operating on high sulfur coal (without conditioner) and on low sulfur coal (with and without conditioner). Sulfur oxides (SOx), ammonia, organics, particulates, flyash resistivity, and ESP power supply values were measured during each test period. During conditioner injection, the low sulfur coal flyash resistivity was reduced about 60%, although the ESPs responded slowly to this change and its effect was not clearly evident during the test period. The results of the SOx, ammonia, and particulate measurements were inconclusive due both to insufficient precision for the number of field tests and to the effect of boiler transients. It is unlikely that the ESP will meet particulate standards when low sulfur coal is burned even if the conditioner is used under test conditions. The test provided useful background information for planning. More thorough testing at Montour seems warranted.

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EFFECT OF A FLYASH CONDITIONING AGENT ON POWER PLANT EMISSIONS

by

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SECTION 1

INTRODUCTION

The combustion of moderate to low sulfur coal to meet sulfur oxide emission standards increases the difficulty of particle collection in electrostatic precipitators (the most common particulate collection device for coal-fired boilers). The difficulty is caused by an increase in dust electrical resistivity at normal ESP temperatures when moderate to low sulfur coal is burned. The increase in dust resistivity is generally believed to be due to low concentrations of sulfur trioxide (SO_3) in flue gas from combustion of moderate to low sulfur coals. Because of the increase in resistivity when low sulfur coal is burned, switching a boiler/ESP system designed for high sulfur coal to low sulfur coal will result in increased particulate emissions unless action is taken to either increase the specific collector area of the electrostatic precipitator or reduce the resistivity of the flyash.

Resistivity modification by injecting a chemical conditioning agent into the flue gas is one method of reducing the impact of coal switching. Data on the effectiveness and environmental impact of conditioning agents are rare.

This study was undertaken as a preliminary program to add to the limited data base on emissions of conditioning agents and on the effectiveness of conditioning agents for restoring electrostatic precipitator performance after a switch from high sulfur to low sulfur coal. The tests were conducted at Pennsylvania Power and Light Company's Montour Station where a proprietary conditioning agent, LPA 402A (Apollo Chemical Company), was being used to improve electrostatic precipitator performance.

The objectives of the program were:

1. To obtain data on overall emissions (gaseous and particulate) when LPA 402A was injected.

2. To obtain data on the effectiveness of the electrostatic precipitator in collecting the conditioning agent.
3. To obtain data on electrostatic precipitator particulate collection when high sulfur coal and low sulfur coal with conditioning and low sulfur coal without conditioning were burned.

Primary emphasis of the program was placed on objectives 1 and 2. Much of the data for objective 3 are questionable because insufficient time was available for the electrostatic precipitator to reach steady-state operation when low sulfur coal without conditioning was used.

CONCLUSIONS

The data reported indicate that:

1. The electrostatic precipitator at Montour operated efficiently when high sulfur coal was burned and could meet the required particulate emission standards.
2. The combustion of low sulfur coal produced a high resistivity flyash with the expected deterioration of ESP electrical conditions.
3. The injection of Apollo Chemical's conditioning agent LPA 402A reduced the ash resistivity from 10^{11} ohm-cm to 4×10^{10} ohm-cm.
4. The injection of LPA 402A may have resulted in increased emissions of sulfur trioxide and ammonia compared with unconditioned low sulfur coal data.
5. It is unlikely that the ESP can meet particulate emission standards when low sulfur coal is burned even when the flue gas is conditioned with LPA 402A under conditions similar to those during the tests.
6. The techniques for measuring flue gas concentrations of sulfur trioxide lack the precision necessary to determine, with a high statistical confidence, differences in sulfur trioxide emissions with and without conditioning.
7. The in-situ flyash resistivity data provide the best evidence of the effects of conditioning with LPA 402A.
8. The techniques for measuring particle size distribution do not have the precision necessary to determine, with a high statistical confidence, differences in particle collection efficiency as a function of particle diameter due to changes in operating conditions.
9. Electrostatic precipitators generally respond slowly to changes in flyash resistivity.
10. There is no significant difference between ESP inlet and outlet SO_3 concentrations.

11. The data provide useful background information for planning future tests.

12. Additional testing at Montour is warranted.

The data taken during these tests do not show an improvement in ESP performance when LPA 402A was used to condition the high resistivity flyash. This is probably due to the fact that insufficient time was available to allow the ESP to respond to the change in ash resistivity when the boiler was switched from high sulfur to moderate sulfur coal. Data reported by Cragle (1976), showing an improvement in ESP performance when LPA 402A was used as a conditioning agent, are consistent with the resistivity data and ESP computer modeling calculations in this report.

SECTION 2

RECOMMENDATIONS

Additional data are necessary on the impact of flue gas conditioning on overall pollutant emissions from coal-fired power plants. Such data are required in the near future to achieve a rational approach to simultaneous compliance with sulfur oxide and particulate emission standards.

Companies desiring to use conditioning to improve ESP performance should conduct careful studies to determine the impact of the conditioning agent on all air pollutant emissions. Studies should also be conducted to ensure that use of a conditioning agent does not create water pollution problems due, for example, to leaching of the agent from flyash disposal piles.

Improvements are necessary in measurement techniques for sulfur trioxide, ammonia, and particle size distributions. Available techniques provide useful answers; but their precision under field use is inadequate to detect differences in emissions under various conditions with a high degree of statistical confidence. The need for improved instruments cannot be over-emphasized.

Future tests should be carefully designed to determine the effectiveness and environmental impact of conditioning agents to improve ESP performance. Simultaneous inlet and outlet measurements should be made whenever possible. If simultaneous or near-simultaneous measurements are impossible, randomization of sampling location for each sample should be used to avoid bias caused, for example, by changing boiler load. Secondary voltage-current data should be obtained for each electrical section for each testing day. Several days operation between tests should be allowed to enable the ESP to reach steady-state when flyash resistivity is changed. Secondary voltage-current data can be used to determine when steady-state is reached.

Research is needed to determine the mechanisms that cause conditioning to change flyash resistivity.

SECTION 3

EMISSIONS TESTS

DESCRIPTION OF THE PLANT

The tests were conducted at Pennsylvania Power and Light Company's Montour Station. All tests were performed on unit number 2, a 750 megawatt coal-fired boiler.

Particulate emissions are controlled by an electrostatic precipitator in a Chevron configuration. The total plate area is 42809.7 m^2 (460,800 ft^2). There are 16 transformer-rectifier (TR) sets and each TR set supplies 2675.6 m^2 (28,800 ft^2) of plate area. The design efficiency of the precipitator is 99.5 percent when 1.5 percent sulfur coal is burned (Cragle, 1976).

The conditioning agent is injected before the air heater where the flue gas temperature is ~ 510°C (950°F) at full load (Cragle, 1976). The normal injection rate is 95 liters per hour (25 gallons per hour).

TEST SCHEDULE

The Montour test program was conducted as described in Table 1. At the onset of the program, December 10 and 11, low sulfur coal was burned and the LPA 402A was injected at 95 liters per hour (25 GPH). From December 16 through December 17, high sulfur coal was burned without injection of the additive. On December 18, 1975, the plant was switched back to low sulfur coal, but the additive was not injected. Water was injected at 95 liters per hour (25 GPH) during this low sulfur run.

Table 2 presents the test plan for Montour. The 5 cfm cyclone train was not used due to damaged connector threads. The remainder of the plan was followed. Additional details of the test plan are contained in Appendix A.

TABLE 1. TEST SCHEDULE

December 8 and 9	Arrive at plant and set up.
December 10 and 11	Full load tests using low sulfur coal, conditioner LPA 402A injected.
December 12	No tests; crew returns to Research Triangle Park, N.C.
December 13 and 14	Weekend, no tests.
December 15	Crew returns to plant.
December 16	Full load tests using high sulfur coal, no additive injected.
December 17	Full load tests using high sulfur coal, no additive injected.
December 18	Full load tests using low sulfur coal, water injected.

TABLE 2. TEST PLAN

Test	Location	No. Per Day	Time Per Test
Dust Resistivity SRI Probe	ESP Inlet	3	2-3 hrs
Particle Size Distribution using Brink Impactors	ESP Inlet	4	1/2-1 hr
Particle Size Distribution using Andersen Impactors and 5 cfm Cyclone Train	ESP Outlet	4	1-2 hrs
SO_2/SO_3 and NH_3	ESP Inlet & Outlet	2	4
Organics	ESP Inlet & Outlet	2	4
Opacity	ESP Inlet EPA Instrument		Continuous
Opacity	ESP Outlet PP&L Instrument		Continuous

TEST METHODS

The test methods used during the tests are fully discussed in Appendix A. An abbreviated discussion of the test methods is presented here.

Ammonia

The ammonia concentration in the flue gas during the Montour test was determined by a modified Kjeldahl-Titrimetric Procedure which was developed by EPA personnel. It is based on the absorption of the ammonia in impingers which contained a sulfuric acid solution. After the sample is complete, free ammonia is distilled into a flask and a titration procedure followed to determine the ammonia concentration. EPA personnel have determined that this method of ammonia concentration determination has acceptable accuracy above about 10 ppm.

Sulfur Oxides

Sulfur oxides were collected by a sample train based on absorption of sulfur trioxide in an isopropanol (IPA) solution and absorption of sulfur dioxide in a H_2O_2 solution. Collection of the SO_x was followed by titration using the IPA-Thorin technique. This method of sulfur oxides determination has been widely used and found to be reliable.

Comparison of the Montour sulfur oxides concentration data with similar data taken at other plants indicates that the Montour data are reasonable. The variability in the SO_2 measurements at Montour is consistent with that found at other locations while the coefficients of variation of the SO_3 measurements are somewhat larger than the norm.

Organics

The composition of organic vapors which might be present in the flue gas was of interest because of possible undesirable decomposition products from the injected additive. The organic vapors were absorbed onto a polymer medium, Tenax GC, and later desorbed into a smaller volume for analysis. With the Montour tests, about 1415 liters of gas was passed through the absorbent and the organics which were collected were desorbed into about 120 ml of pentane. The extract was analyzed in two different ways. Fourier Transform infrared spectroscopy was used to provide a qualitative analysis. A linked GC/mass spectroscopy analysis was used to detect diethylnitrosamine, which was thought to be a likely decomposition product.

This technique for analysis of nitrosamine in the flue gas is extremely sensitive. Its detection limit under the conditions used during this test is less than 5 parts per trillion.

Particulate Size Measurement

Cascade impactors (inertial sizing devices) were used to determine particulate size distributions at Montour. The Brink Impactor, a low sample rate device, was used on the inlet to the electrostatic precipitators (ESP); the Andersen impactor, a high sample rate impactor, was used on the outlet. Isokinetic sampling procedures were followed with both impactors. The Andersen impactor used the factory precut glass fiber substrates. Foil substrates, coated with polyglycol grease, were used as substrates in the Brink impactor.

The fiberglass substrates used with the Andersen impactor were preconditioned by in-situ exposure to the flue gas using procedures developed by the Southern Research Institute. Blanks were also run each day with the Andersen impactor. The average weight gain on a blank was used as a correction on that day's Andersen stage weights. Blanks were not run with the Brink impactor.

Flyash Resistivity

The resistivity of the flyash was measured using an in-situ point-to-plane resistivity probe and the reported results were obtained using the parallel disc method. The point-to-plane probe simulates dust collection as it occurs in an ESP, and is thought to be more relevant to precipitator performance than is data derived from mechanically collected dust. The resistivity is determined from the electrical characteristics of the dust just prior to sparkover. Flyash resistivity measurements as made at Montour have a precision of around ± 30 percent.

Electrical Measurements

During the test, primary voltages, primary currents, and spark rates for the 16 transformer-rectifier sets on the number 1 unit were recorded once per shift. The results of these measurements are contained in Appendix B. Secondary current meters were not available during the test. Secondary voltage readings were obtained during testing for operation with high sulfur coal, with a lower sulfur coal with Apollo Chemical Company additive LPA 402A and with a low sulfur coal with the addition of water.

The secondary voltage readings were made with a voltage divider probe consisting of a 120 MΩ resistor and a 12kΩ resistor connected in series. The probe was calibrated against a commercial high voltage meter with a 1 percent accuracy prior to the test. (A calibration factor of 9.40×10^3 was determined for voltage read across the 12kΩ resistor.) Secondary voltages read during the test are estimated to be accurate to ±0.5 kV. Secondary voltage-current characteristics were generated for each test condition for the 1-2 chamber of the precipitator. The results of these measurements are contained in Appendix C. These V-I characteristics were generated by turning off the power set, installing the voltage divider, than manually turning up the power. The corresponding primary voltages, currents, and secondary voltages were then recorded as the primary voltage input was manually decreased. Estimates of the secondary currents were than calculated by assuming that the secondary power output was 60 percent of the primary power input. Typically, transformer-rectifier sets have conversion factors from 40 percent to 80 percent. By assuming a value of 60 percent, the estimated possible error in the calculated secondary currents is on the order of 33 percent. The average current densities to the precipitator plates for each power set were calculated using the above assumption of 60 percent power conversion and the following procedure.

The primary voltage and current were multiplied to obtain primary power. The primary power was then multiplied by 0.6 and divided by the secondary voltage to obtain secondary current, which was in turn divided by 2.68×10^7 cm, the plate area supplied by each power set.

SECTION 4

RESULTS AND DISCUSSION

GASEOUS EMISSION TESTS

The results of the gaseous emission tests using all the data are summarized in Table 3. The data taken at Montour show considerable scatter as is shown by the large standard deviations in Table 3. Harris, in Appendix A, has examined the data taken at Montour and eliminated some of the data points. Table 4 is a summary of the data with the data points outside the 90 percent confidence limits deleted. See Appendix A for the details of how the points were deleted.

Ammonia Data

The data clearly show that injection of LPA 402A caused emission of ammonia. The exact concentration of the ammonia emissions is uncertain due to the scatter in the data. The measured ammonia concentrations are below the useful detection limits of the ammonia test method; i.e., the accuracy and precision of the method at these concentrations is low.

Sulfur Trioxide Data

There is no statistically significant difference between the inlet and outlet sulfur trioxide data for the three test conditions. This is in agreement with SO_3 data taken by others at other power plants; e.g., Dismukes (1975). Therefore, the inlet and outlet SO_3 data for each test condition were combined and averaged in order to make comparisons between test conditions.

The flue gas SO_3 concentration with conditioned low sulfur coal is the same as the flue gas SO_3 concentration with high sulfur coal.

TABLE 3. SUMMARY OF GASEOUS EMISSION TEST DATA AT MONTOUR USING ALL DATA

Coal and Condition	SO_2 ppm ESP Inlet	SO_2 ppm ESP Outlet	Combined SO_2 ppm	SO_3 ppm ESP Inlet	SO_3 ppm ESP Outlet	Combined SO_3 ppm	NH_3 ppm ESP Inlet	NH_3 ppm ESP Outlet	Combined NH_3 ppm
High Sulfur No Conditioning	1340.2 (84.6)	942 (136.6)	1140.9 (237.6)	28.8 (20.9)	25.6 (10.3)	27.2 (15.3)	0[a]		0[a]
Low Sulfur with Injection of LPA 402A	929.7 (97.1)	842 (75.6)	881.9 (93)	27.2 (8.4)	30 (19.8)	28.8 (15)	3.0 (2.3)	8.1 (9.1)	5.1 (6.8)
Low Sulfur with Injection of Water	680.1 (182.1)	644 (60.7)	663.4 (121)	29.5 (20.8)	16 (6.7)	22.8 (17.3)	0	0	0

Standard deviation of measurements shown in parentheses.

[a] One measurement of 25.4 ppm, 6 measurements of 0.00 ppm of NH_3.

TABLE 4. REVISED SUMMARY OF GASEOUS EMISSION TEST DATA AT MONTOUR WITH DATA POINTS OUTSIDE 90 PERCENT CONFIDENCE LIMITS DELETED

Coal and Condition	SO_2 ppm ESP Inlet	SO_2 ppm ESP Outlet	Combined SO_2 ppm	SO_3 ppm ESP Inlet	SO_3 ppm ESP Outlet	Combined SO_3 ppm	NH_3 ppm ESP Inlet	NH_3 ppm ESP Outlet	Combined NH_3 ppm
High Sulfur No Conditioning	1340 (84.6)	942 (136.6)	1141 (237)	19.5 (11.5)	25.6 (10.3)	2.3 (10.4)	0	0	0
Low Sulfur with Injection of LPA 402A	890 (46.2)	870.4 (34.2)	879 (38.6)	27.2 (8.35)	18.4 (10.0)	23.3 (9.7)	3 (2.3)	8.1 (9.1)	5.5 (6.8)
Low Sulfur with Injection of Water	683 (178.4)	644 (60.7)	663 (121)	16.2 (6.7)	16 (5)	16 (5.3)	0	0	0

Standard deviation shown in parentheses.

The flue gas SO_3 concentration with conditioned low sulfur coal is significantly higher than the flue gas SO_3 concentration with unconditioned low sulfur coal. Based on chemical analysis of LPA 402A, the measured increase in flue gas sulfur trioxide concentrations is reasonable. However, it is not clear that all the increase in sulfur trioxide emissions is due to injection of LPA 402A. The sulfur dioxide data indicate that the coal sulfur content may have changed. Thus, some of the increase in sulfur trioxide emissions may be due to a change in coal sulfur content.

Sulfur Dioxide Data

The sulfur dioxide data for the high sulfur coal tests show a significant difference between inlet and outlet sulfur dioxide concentrations. The inlet and outlet data were taken on separate days so a reasonable explanation for the change in sulfur dioxide concentration is a change in coal sulfur content.

There is no reason to expect significant removal of sulfur dioxide in an electrostatic precipitator. It is true that ionized sulfur dioxide molecules could be removed by the electrostatic precipitator. However, for the current density and sulfur dioxide concentrations at Montour, the possible number of sulfur dioxide molecules that could be removed by ionization and collection is insignificant. Calculations supporting this statement are included in Appendix D.

The sulfur dioxide concentrations during the tests where LPA 402A was injected are significantly higher than the sulfur dioxide concentrations for low sulfur coal without injection. Injection of LPA 402A could not increase the sulfur dioxide concentration to the level indicated. Thus, the increase in sulfur dioxide concentration is probably due to an increase in coal sulfur content.

Organic Data

Qualitative analysis by infrared spectroscopy identified three compounds which might be decomposition products of the LPA 402A. These were a carboxylic acid, a salt of the carboxylic acid, and a possible alkanol amine. The quantitative analysis for diethylnitrosamine showed that the nitrosamine concentration was less than the detection limits of the analysis method (less than 5 parts per trillion).

PARTICLE SIZE DATA

Particle size distributions at both the inlet and the outlet of the ESP were determined for all three types of firing. The inlet data were fairly consistent throughout the test. Coal type and boiler variables had little apparent effect on the inlet size distribution. There was a great deal more variation in the outlet particulate data, both within a given data set and from day to day.

Average inlet and outlet particle size distributions by mass are presented in Figures 1 and 2. Note that the outlet particle size distribution by mass for unconditioned low sulfur coal shows lower mass concentrations for all particle diameters than shown by the size distribution curves for the other two test conditions. As explained in the section on electrostatic precipitator efficiency, this is probably due to failure of the electrostatic precipitator to reach steady-state operation after the switch from high to low sulfur coal. Cragle (1976) reports that several days operation is required for the electrostatic precipitator at Montour to reach steady-state following a change in coal type.

Inlet and outlet size distributions for all test conditions are presented in Appendix A. An examination of the data in Appendix A shows that the data for particles with diameters less than about 2 microns are generally more uncertain than the data for larger particle diameters.

DUST RESISTIVITY DATA

The results of the ash resistivity tests are presented in Figure 3. The injection of LPA 402A reduced the resistivity of the low sulfur coal flyash by about 60 percent.

Extrapolation of the ash resistivity versus temperature data for the LPA 402A conditioned flyash indicates that electrostatic precipitator operation at flue gas temperatures in the range of 137 to 140°C (roughly equivalent to the temperatures when high sulfur coal was burned) would produce ash resistivity of approximately 10^{10} ohm-cm. Such a change in operating temperature should improve the particle collection efficiency of the electrostatic precipitator.

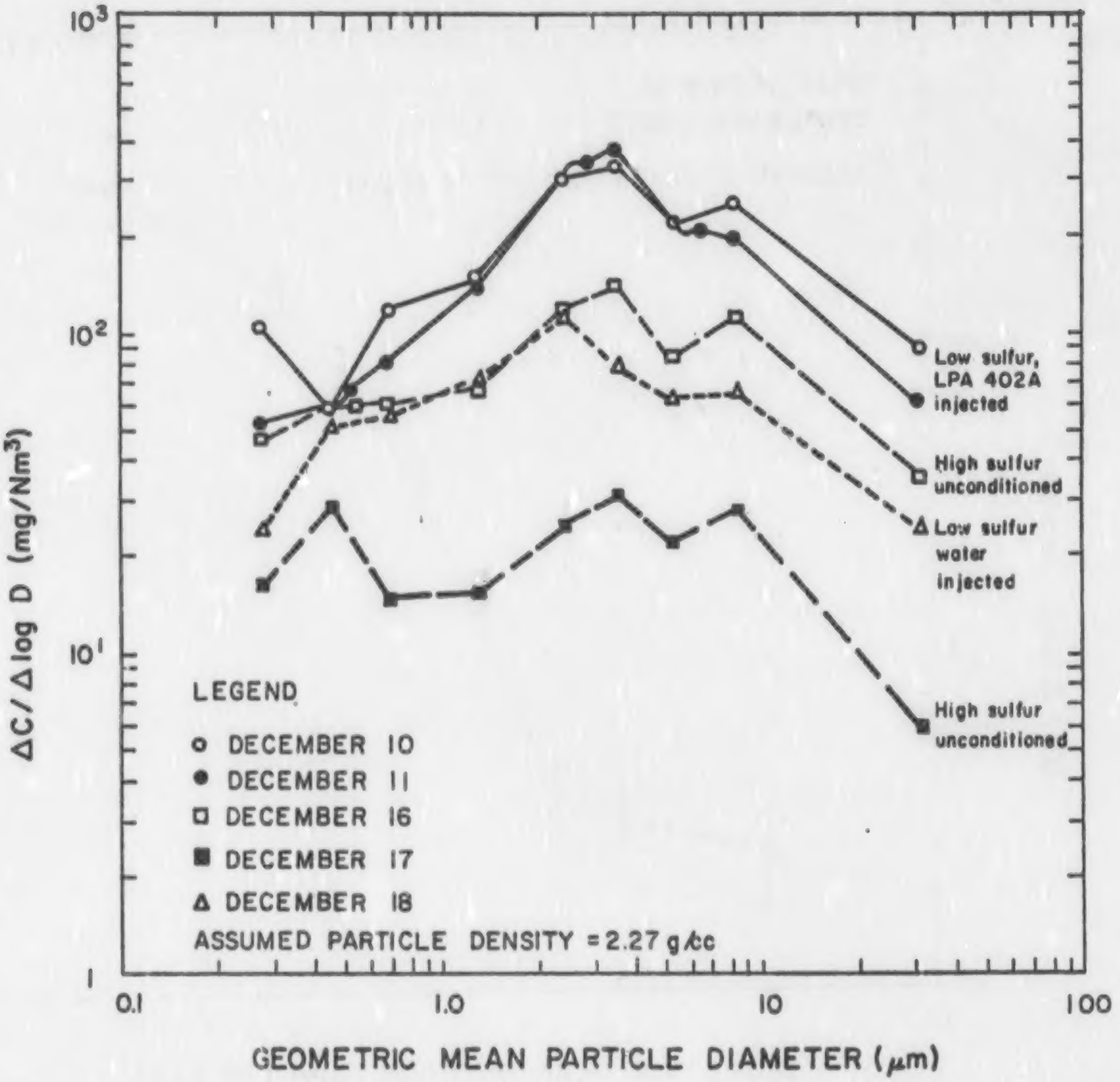

Figure 1. Differential particle size distributions at outlet of ESP, Montour, December 10, 11, 16, 17, and 18, 1975.

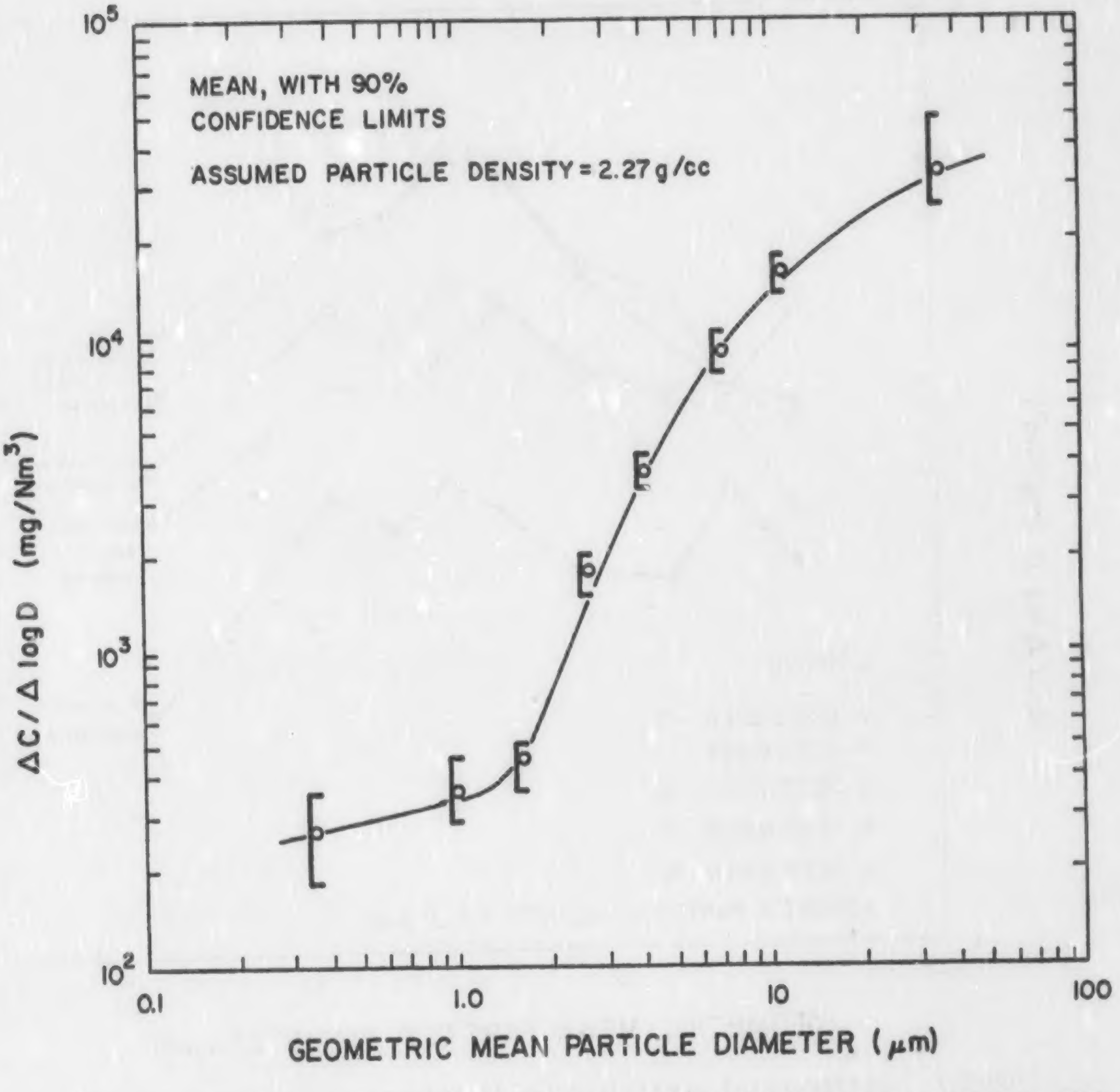

Figure 2. Mean differential particle size distribution at inlet to ESP, Montour Plant, December 10, 11, 16, 17, and 18, 1975.

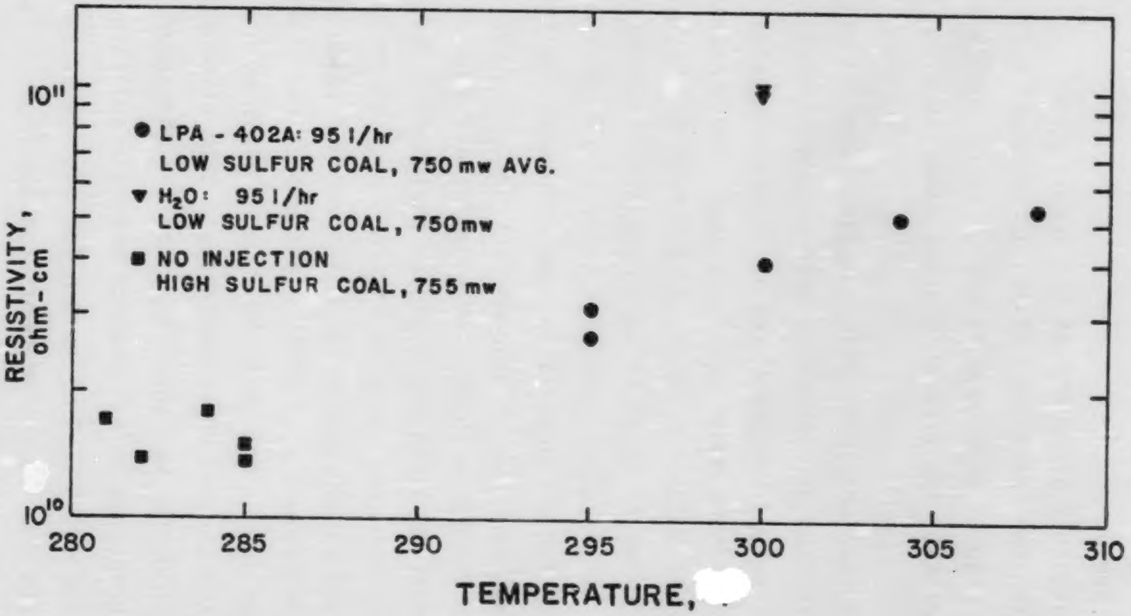

Figure 3. Flyash resistivity measurements, Montour Power Plant.

ELECTRICAL DATA

Voltage-current (V-I) characteristics supply information on the electrical operation of a precipitator and can be used to determine the effect of an additive on precipitator performance. V-I characteristics are sensitive to changes in resistivity, particle size distribution, and grain loadings of the ash entering the unit.

Figures 4 through 7 are plots of the secondary voltage (V)-current density (J) characteristics for the 1A-2A, 1B-2B, 1C-2C, and 1D-2D power sets for each test condition. Figures 8 through 11 are plots of the primary voltage-current characteristics for each of the 1-2 power sets and for each test condition.

The secondary V-J characteristics obtained when burning high sulfur coal with a low resistivity ash appear to have no significant irregularities or unusual behavior, except for power set 1C-2C where secondary voltage jumped 17 kV to 58 kV when input power was increased. The measurements for the 1C-2C unit are probably in error. With the ash from the high sulfur coal, maximum voltages on the order of 39 kV were obtained. The maximum current densities ranged from 14 nA/cm^2 at the inlet to 34 nA/cm^2 at the outlet.

The secondary V-J characteristics obtained with low sulfur coal show possible signs of back corona. Higher current densities were obtained in the inlet for a given voltage with the low sulfur coals than with high sulfur coal. Since the low sulfur coal ash had a higher resistivity than the high sulfur coal ash, the V-J characteristics in Figure 5 show either the presence of back corona or a significant change in the inlet grain loading or particle size distribution. Measurement with Brink impactors at the inlet of the precipitator showed changes in the 0.4 μm to 20 μm particle diameter range that would probably not affect the V-J characteristics. Data below 0.4 μm were not obtained. If back corona was occurring, the V-J characteristics indicated that less back corona was being obtained when the additive was added.

The V-J characteristics in Figure 6 for the low sulfur coal test had abnormal curvatures and the measurements for the high sulfur coal were off scale and are probably in error. There is a possibility that the 1C-2C power supply was not operating properly. The current densities at which sparking occurred indicated a decrease in ash resistivity with the additive.

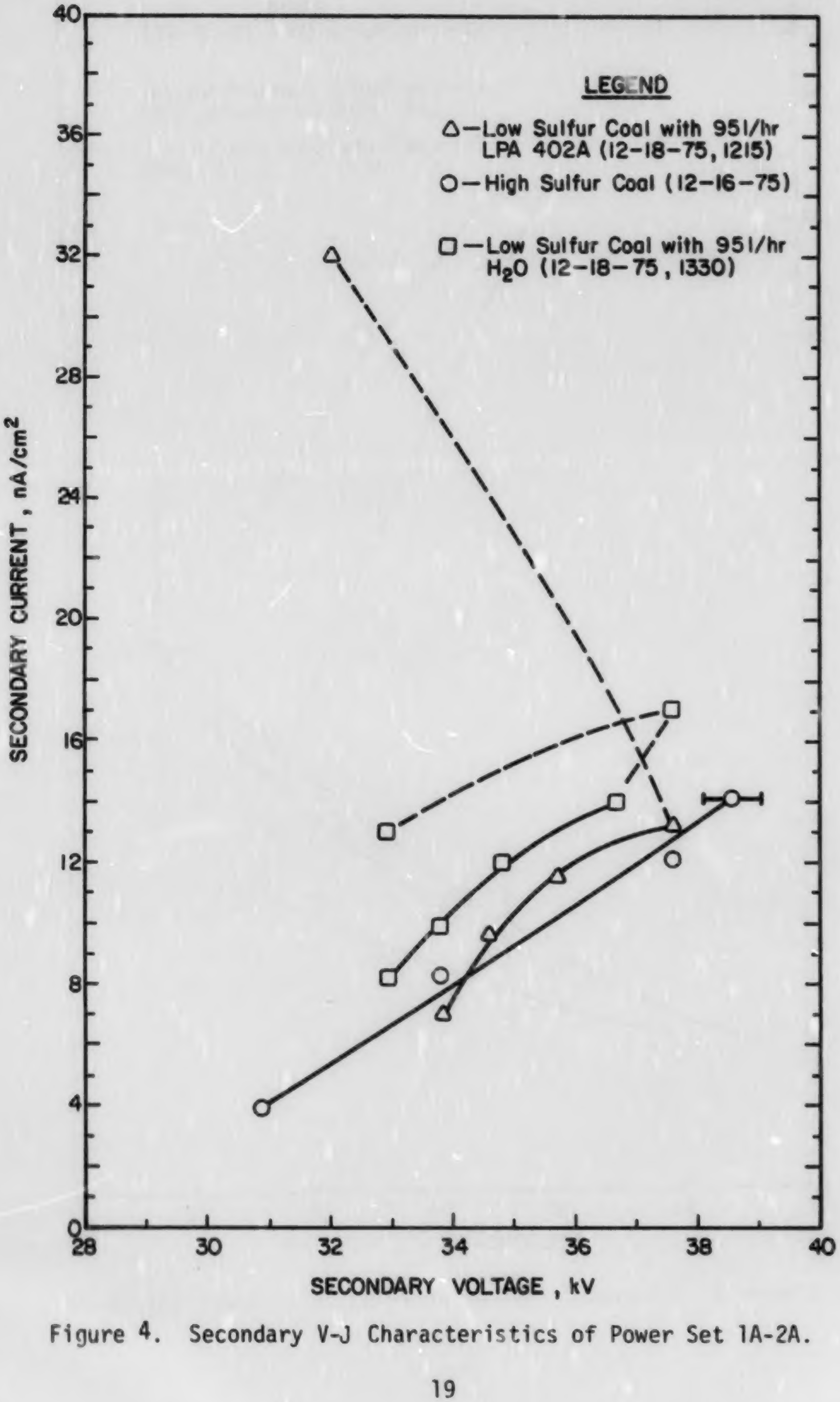

Figure 4. Secondary V-J Characteristics of Power Set 1A-2A.

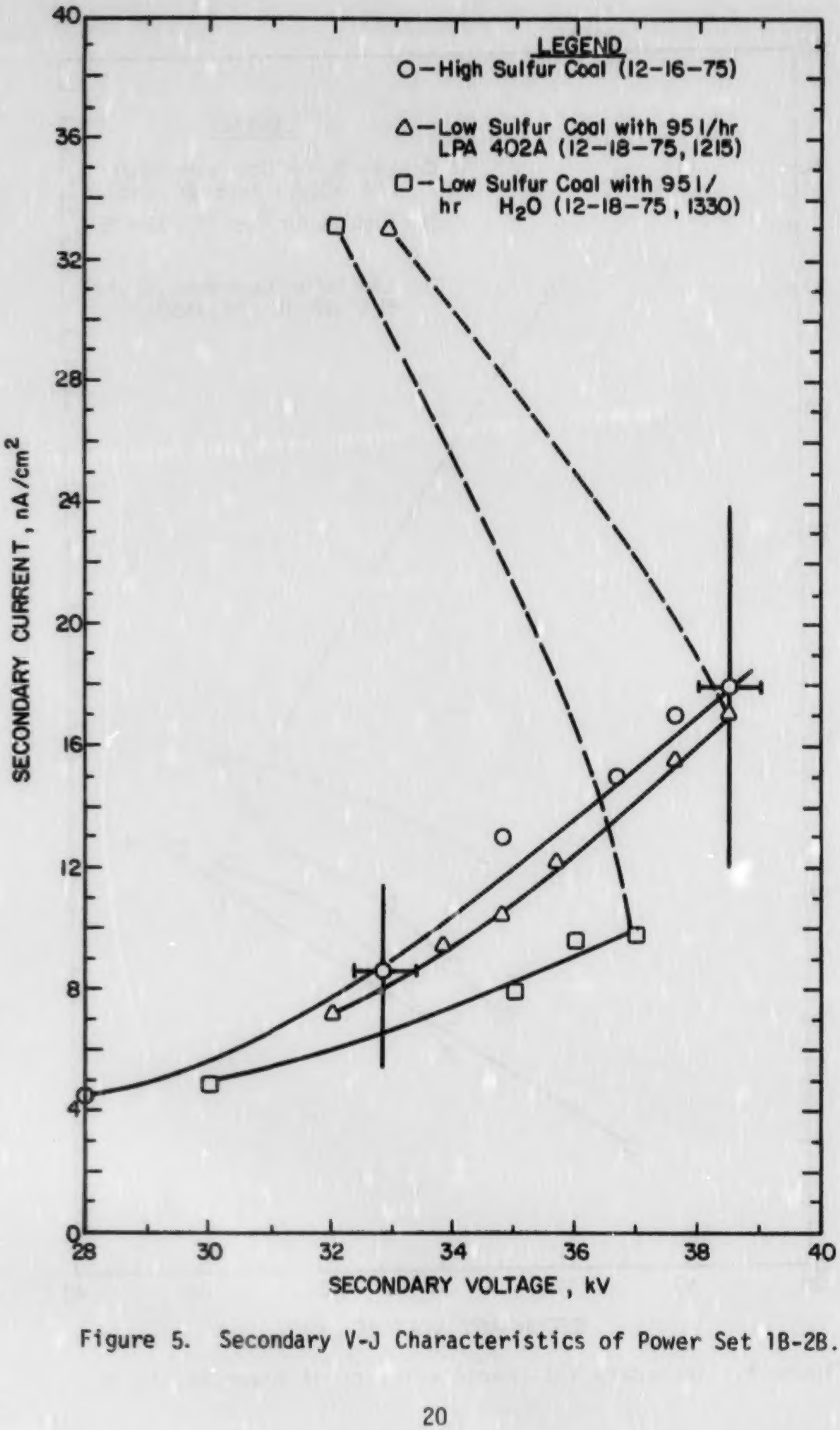

Figure 5. Secondary V-J Characteristics of Power Set 1B-2B.

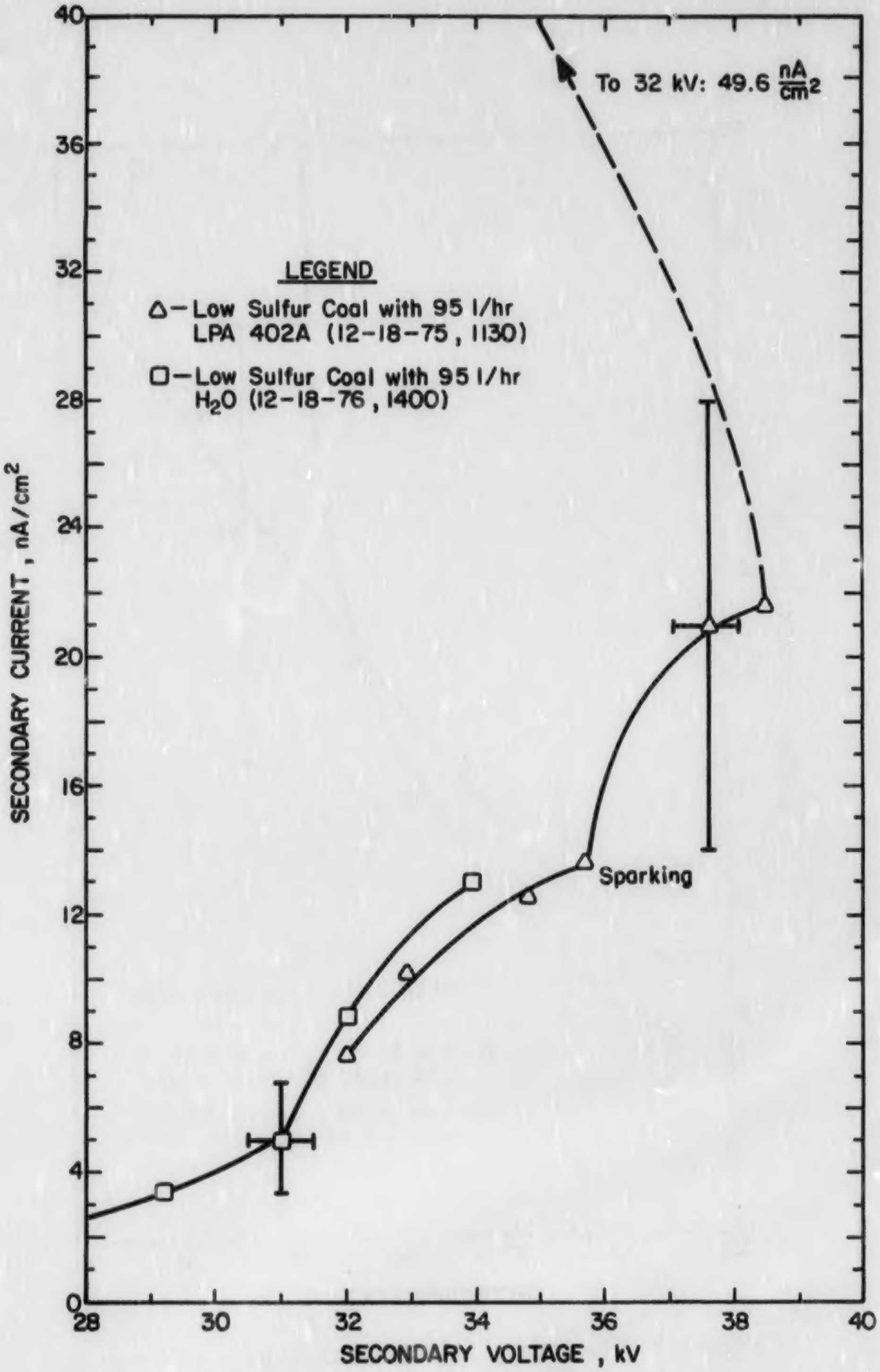

Figure 6. Secondary V-J Characteristics of Power Set 1C-2C.

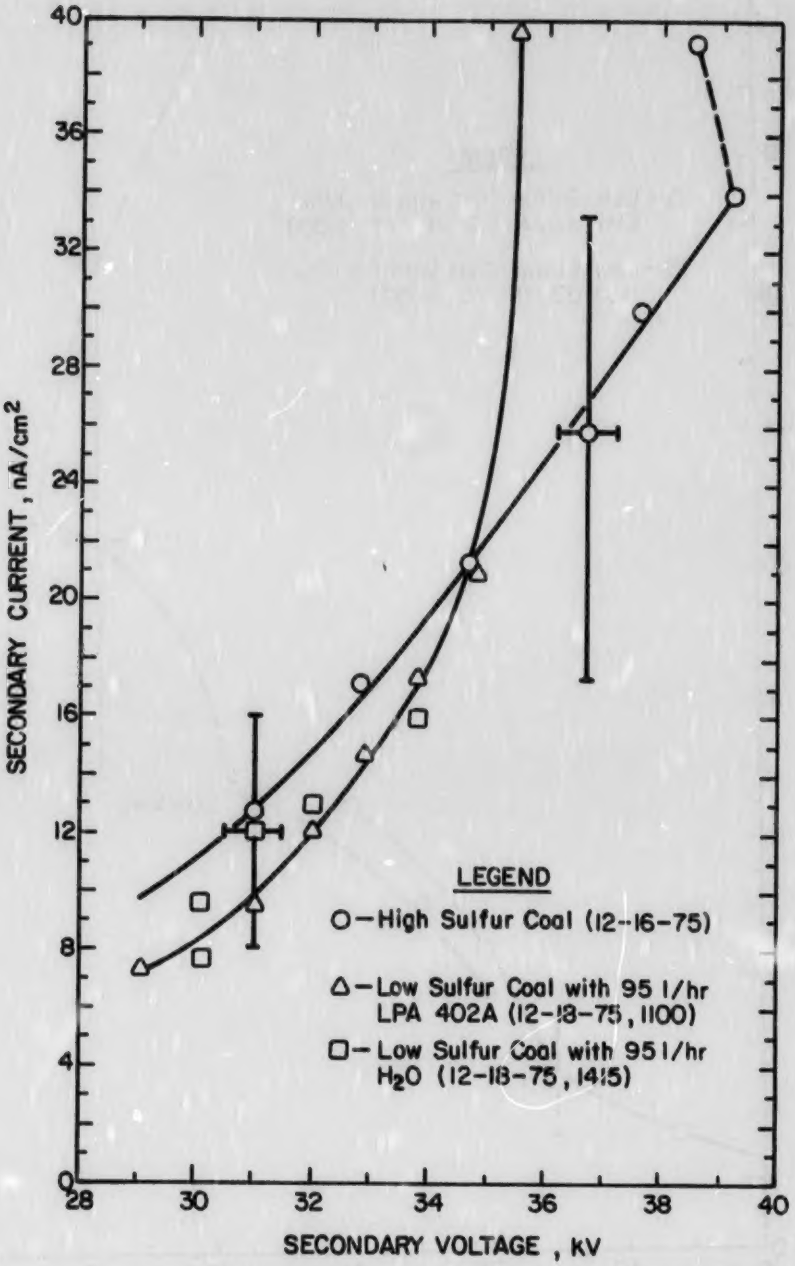

Figure 7. Secondary V-J Characteristics of Power Set 1D-2D.

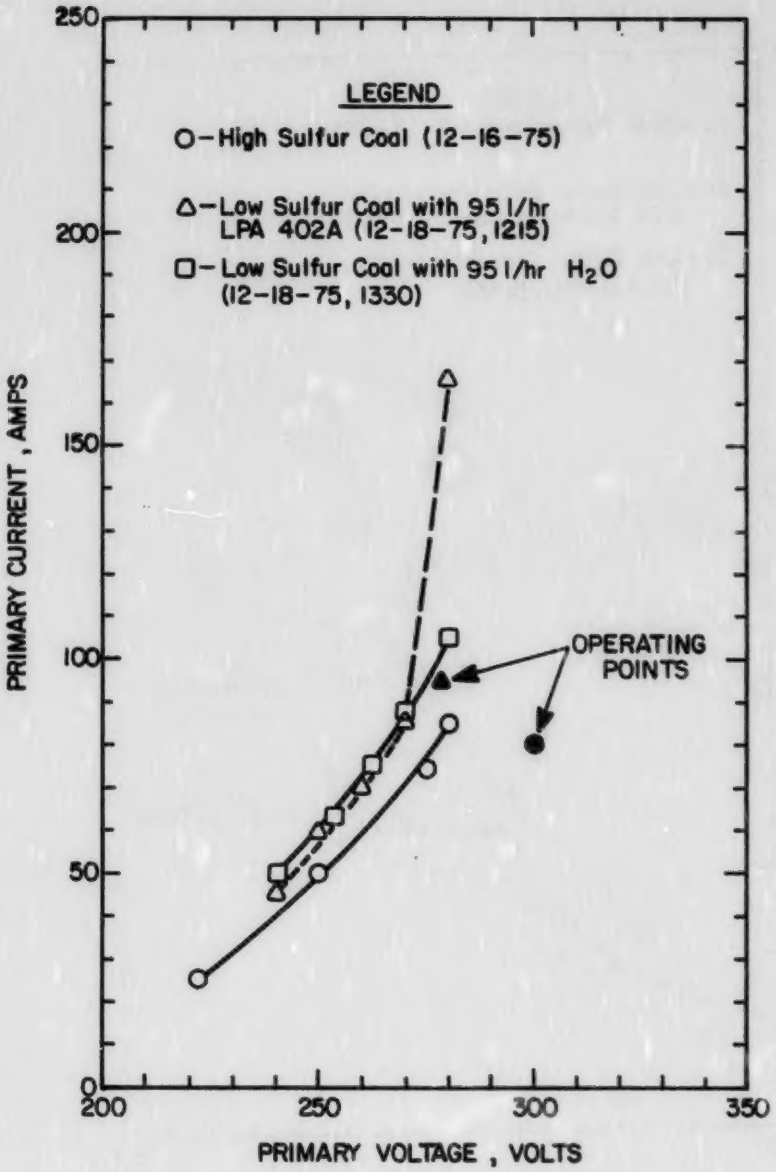

Figure 8. Primary V-I Characteristics, Power Set 1A-2A.

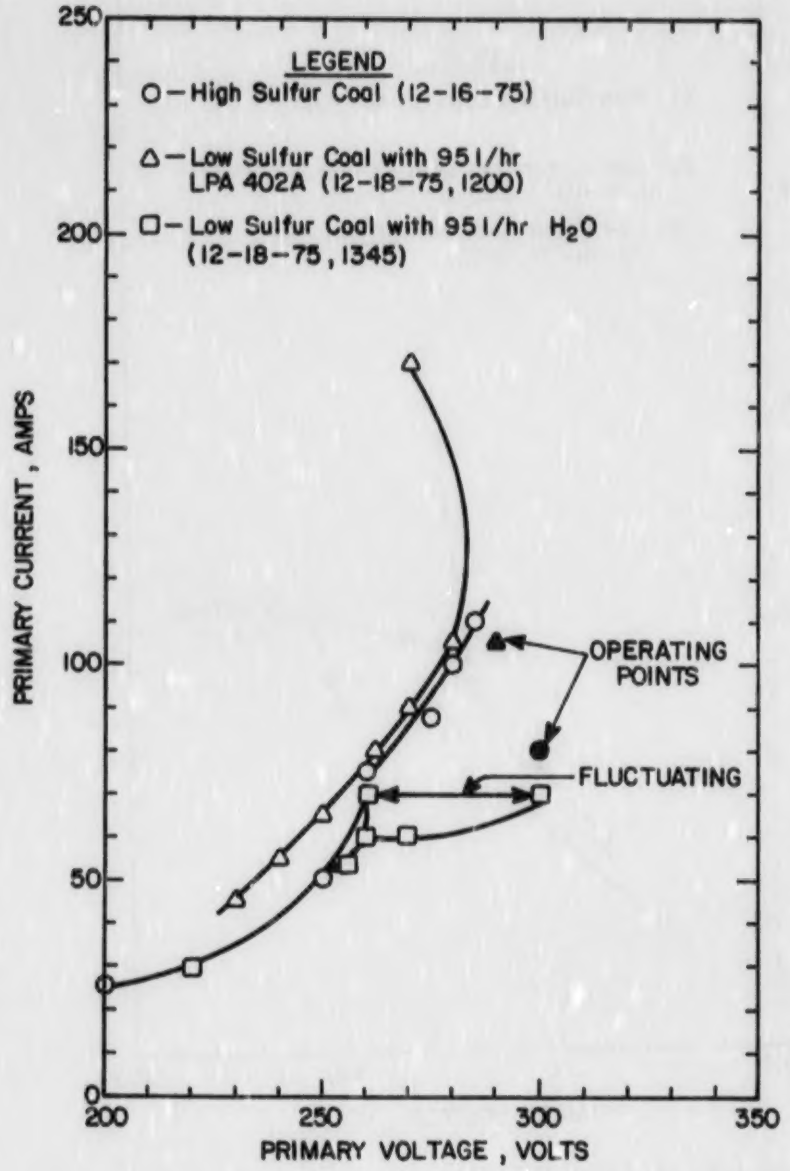

Figure 9. Primary V-I Characteristics, Power Set 1B-2B.

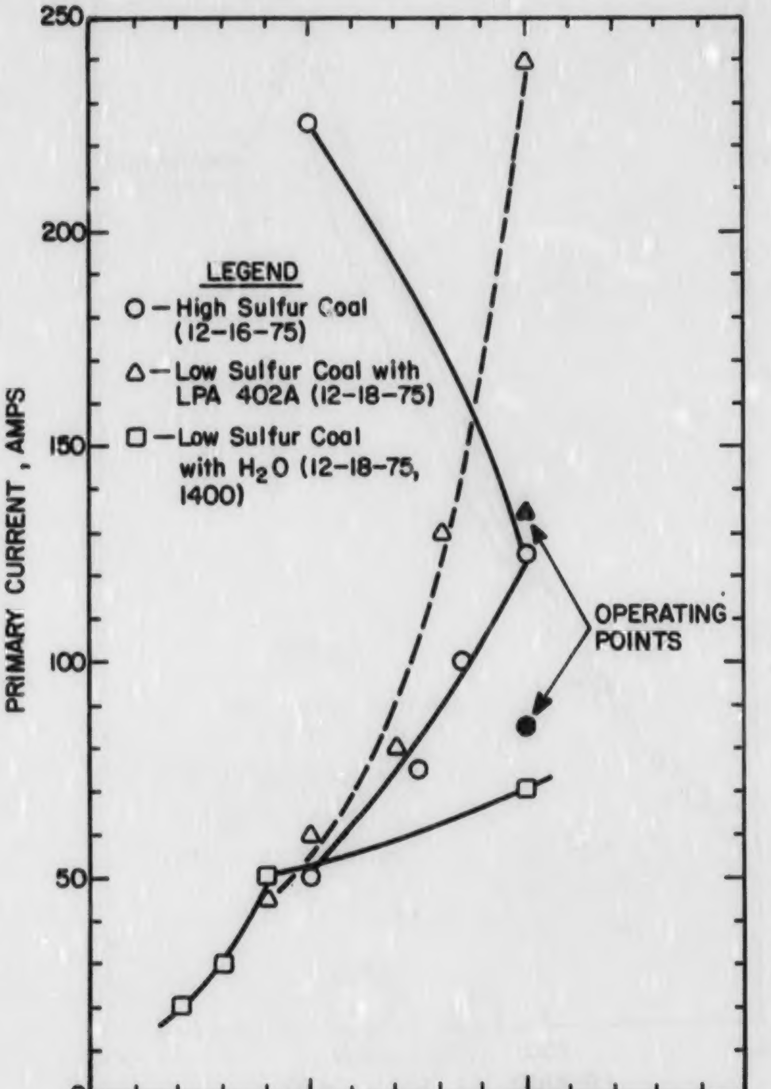

Figure 10. Primary V-I Characteristics, Power Set 1C-2C.

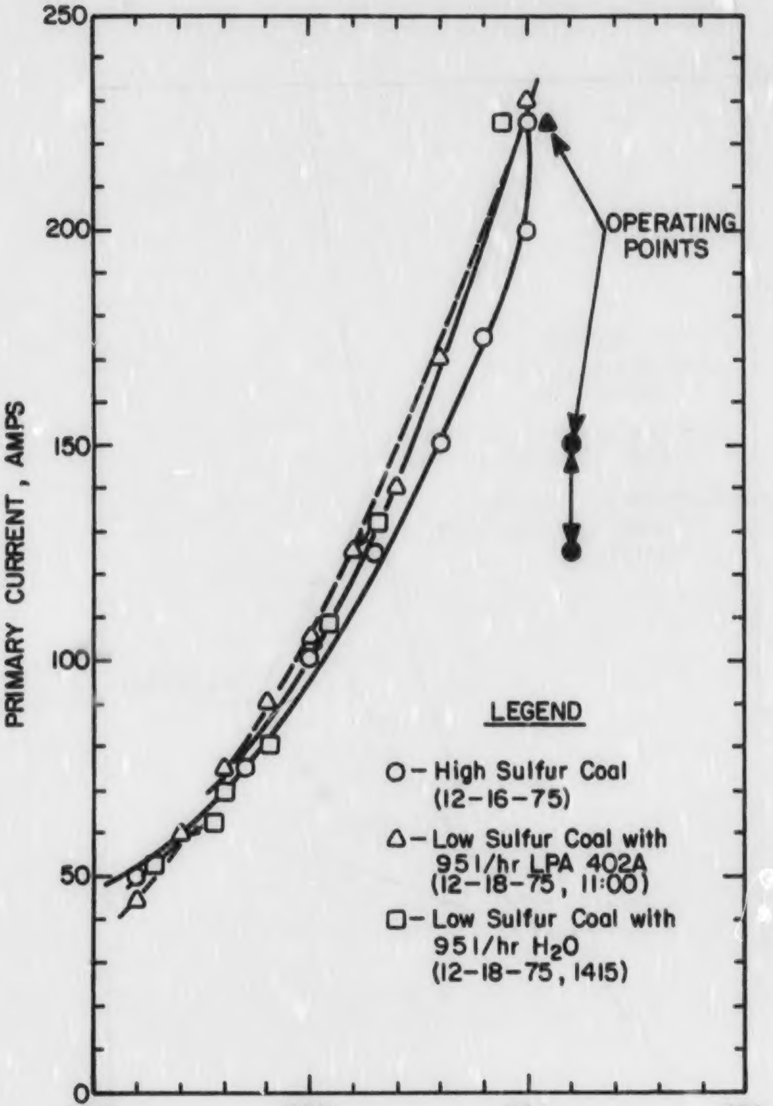

Figure 11. Primary V-I Characteristics, Power Set 1D-2D.

The V-J characteristics for the outlet power set are shown in Figure 7. The low sulfur coal curves with water injection and with the additive injection have the same behavior. Both low sulfur V-J characteristics initially lie below the high sulfur coal V-J characteristics then turn up to cross the high sulfur coal characteristics. This type of behavior indicates the development of back corona for the low sulfur coal ash. The small difference between the low sulfur coal characteristics with water injection and with an additive injection indicates that the additive was not affecting the resistivity of the ash collected in the last section. However, a definite conclusion cannot be made since only an hour was allowed for stabilization between measurements.

The current densities at the break (point at which heavy sparking probably started) in the secondary V-J characteristics are tabulated in Table 5. Significantly higher current densities were obtained with the high sulfur coal. A significant increase in obtainable current density was also observed from the inlet to the outlet of the precipitator. No consistent differences were obtained for the two low sulfur coal conditions; again, the short time between recording of the V-J characteristics is probably responsible for this. The average primary operating power densities for one chamber are tabulated in Table 6. The high sulfur coal with lower resistivity ash had the highest power densities, as expected.

TABLE 5. CURRENT DENSITIES AT BREAK IN SECONDARY V-J CHARACTERISTICS

	In-Situ Resistivity Ω-cm	[a] Current Density 1A-2A nA/cm^2	1B-2B nA/cm^2	1C-2C nA/cm^2	1D-2D nA/cm^2
High sulfur coal	1.5×10^{10}	14	18	b	34
Low sulfur coal, LPA 402A [c]	4.0×10^{10}	13.5	17	13.5-21.6	[d]9-21
Low sulfur coal, H_2O	9.9×10^{10}	14.0	10	13	9-21

[a] At break in V-J characteristics or maximum obtained at all current densities ±33 percent

[b] Abnormal V-J characteristics

[c] Obtained on a December 10, 1975. V-J measured with LPA 402A injection December 18, 1975.

[d] A sharp break in V-J characteristics is not evident; however, back corona probably occurred at a current density less than 21 nA/cm^2.

TABLE 6. AVERAGE OPERATING POWER DENSITIES

	In-Situ Resistivity Ω-cm	Average Primary Power Density, mW/cm^2 1A-2A	1B-2B	1C-2C	1D-2D
High sulfur coal	1.5×10^{10}	1.03	1.04	1.73	2.64
Low sulfur coal, LPA 402A	4.0×10^{10}	0.95	0.94	0.70	1.54
Low sulfur coal, H_2O	9.9×10^{10}	0.86	1.05	0.93	2.24

One chamber selected to correspond with V-J data.

PARTICLE COLLECTION EFFICIENCY

The particle collection efficiency as a function of particle diameter was calculated as described in Appendix E. The results of these calculations are shown in Figures 12, 13, 14, 15, and 16. The 90 percent confidence intervals for each curve are also shown. The confidence intervals were estimated as described in Appendix E.

The confidence intervals for most of the particle collection efficiency versus particle diameter curves are rather broad. As can be seen from Figure 17, much of the data for all five days falls within the 90 percent confidence interval for the December 16, 1975 data. Such broad confidence bands make the statistical interpretation of the data difficult if one desires a high degree of statistical confidence.

The broad confidence interval is probably caused by source; i.e., boiler/electrostatic precipitator system variation and cascade impactor measurement errors. Of these, cascade impactor errors are probably more important.

In future tests the confidence intervals can be reduced by better (i.e., more precise) cascade impactors and/or by taking more data. Because state-of-the-art impactors and techniques for using impactors were used for these tests, it is unlikely that better impactors will be available soon. Thus more data should be taken in future tests.

The efficiency versus particle diameter curves for the high sulfur coal and conditioned low sulfur coal are consistent with the dust resistivity and electrostatic precipitator operating data discussed earlier. The efficiency versus particle diameter curves for the low sulfur unconditioned tests are not consistent with the dust resistivity and electrostatic precipitator operating data.

The data used to calculate the efficiency curve for unconditioned low sulfur coal were taken less than 24 hours after the boiler was switched from high sulfur to low sulfur coal. Such a short time is inadequate to allow the electrostatic precipitator to adjust to the change in dust resistivity. The performance of an electrostatic precipitator is governed, in part, by the electrical resistivity of the dust layers on the collecting electrodes. Several days operating time is required for the resistivity of the collected dust layer to fully respond to a change in particle resistivity.

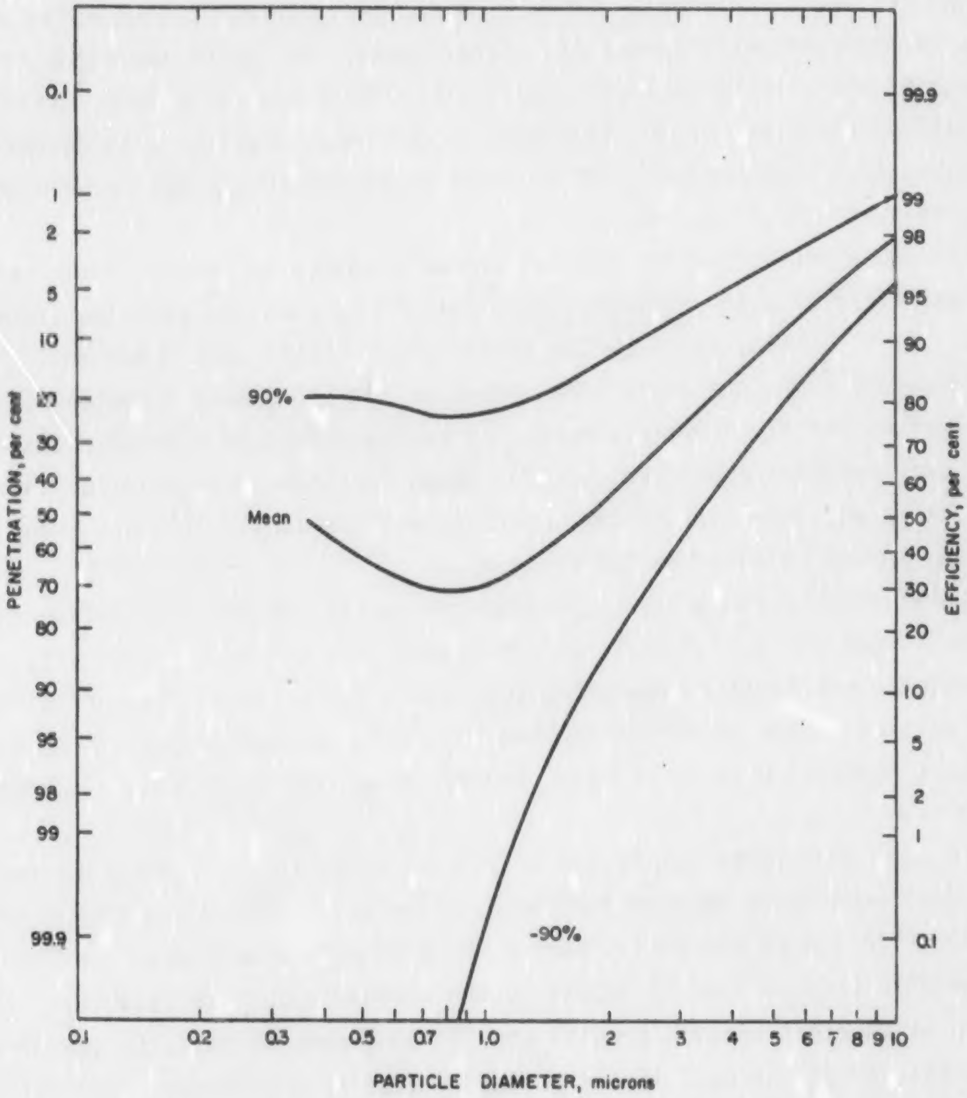

Figure 12. Efficiency versus particle diameter for December 10, 1975. (Low sulfur coal conditioned with LPA 402A).

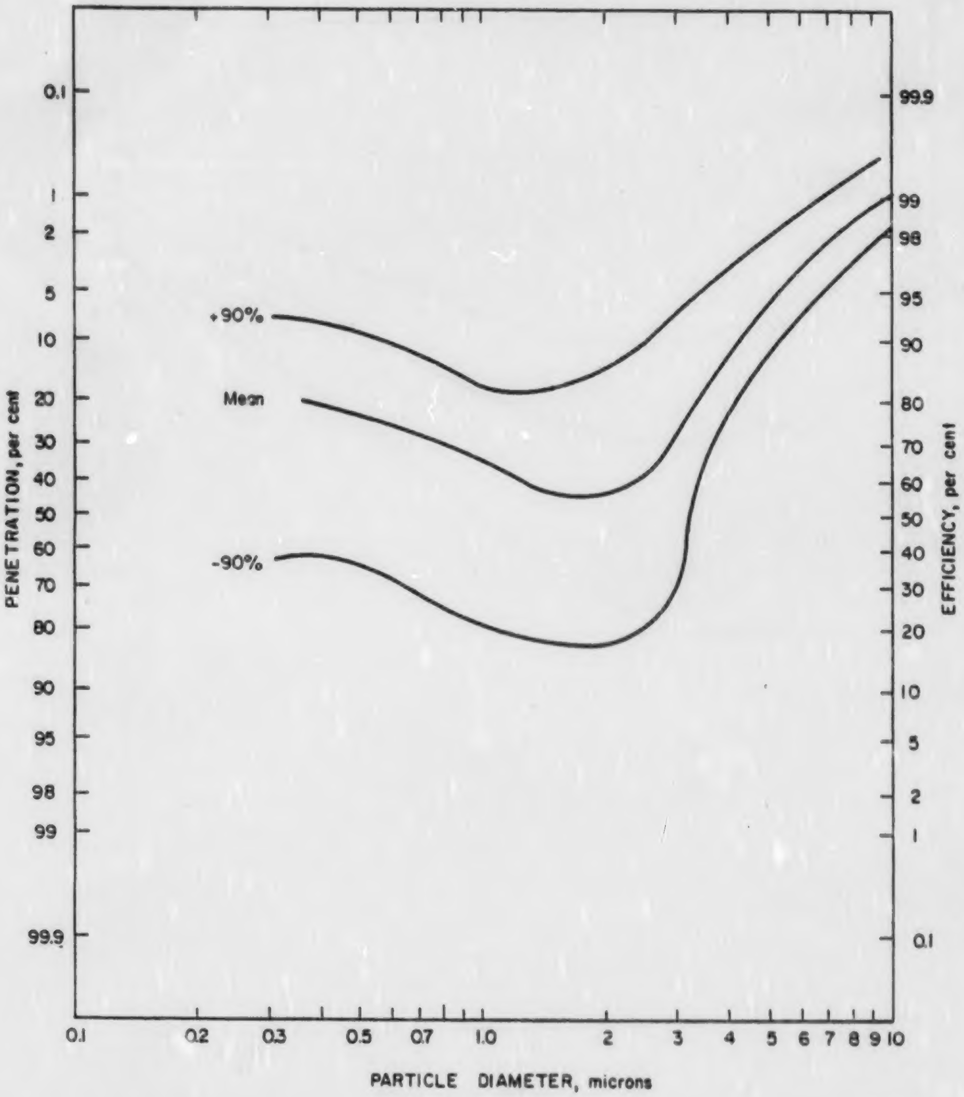

Figure 13. Efficiency versus particle diameter for December 11 (low sulfur coal conditioned with LPA 402A).

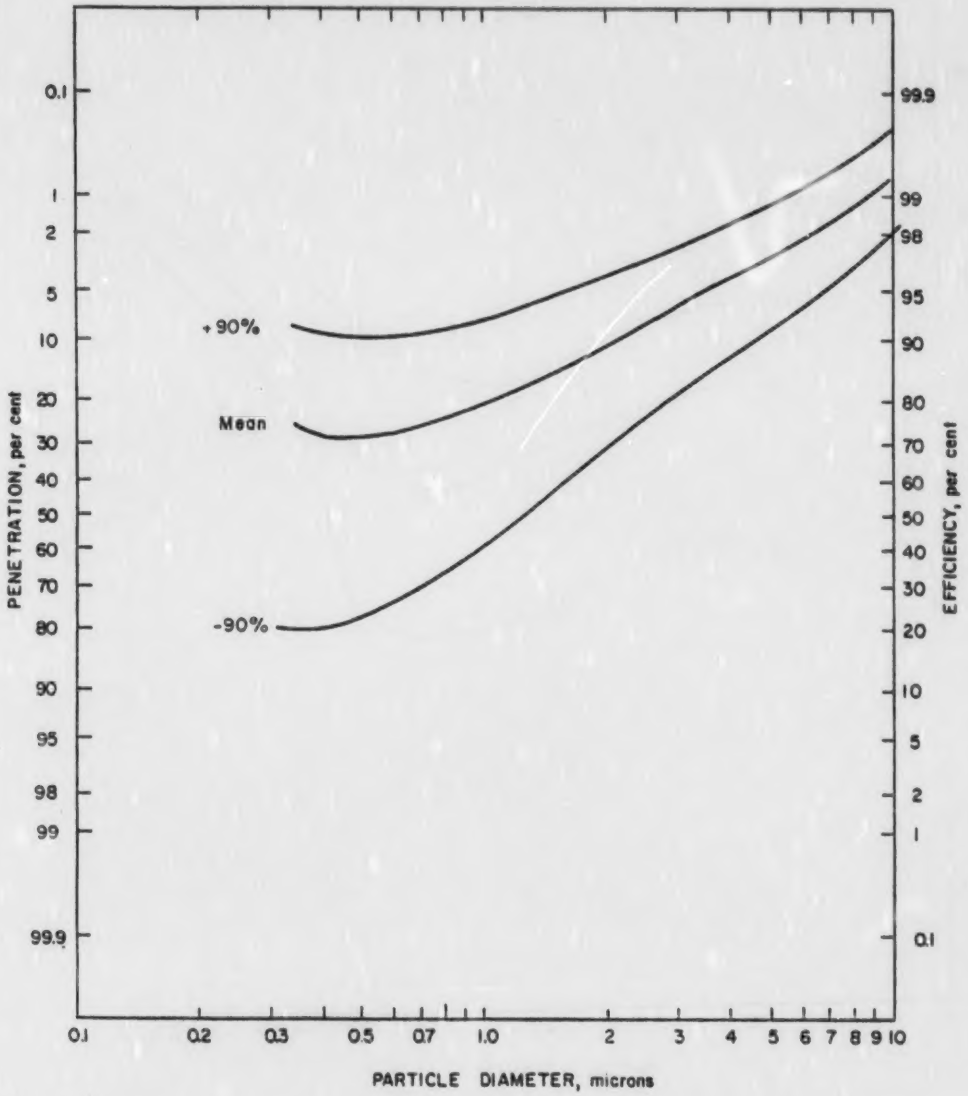

Figure 14. Efficiency versus particle diameter for December 16 (high sulfur coal).

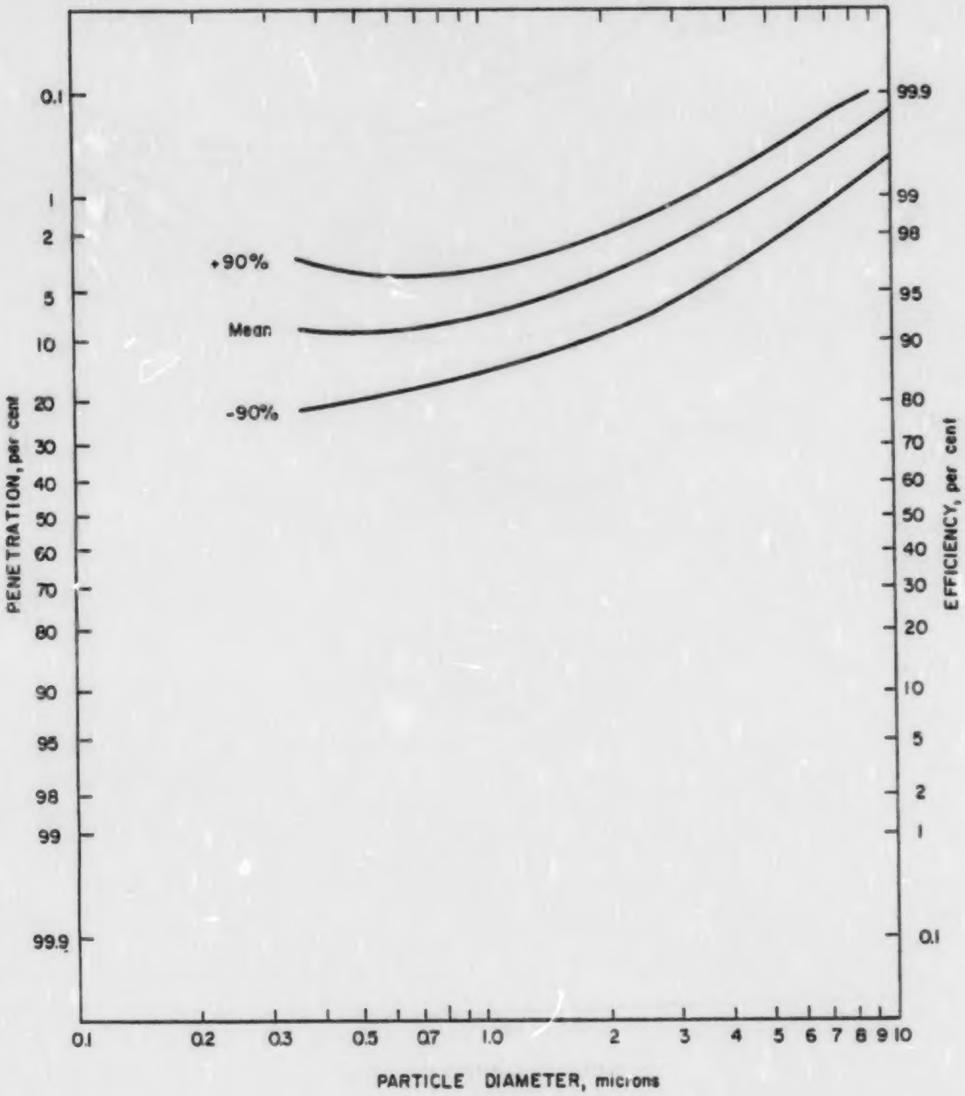

Figure 15. Efficiency versus particle diameter for December 17 (high sulfur coal).

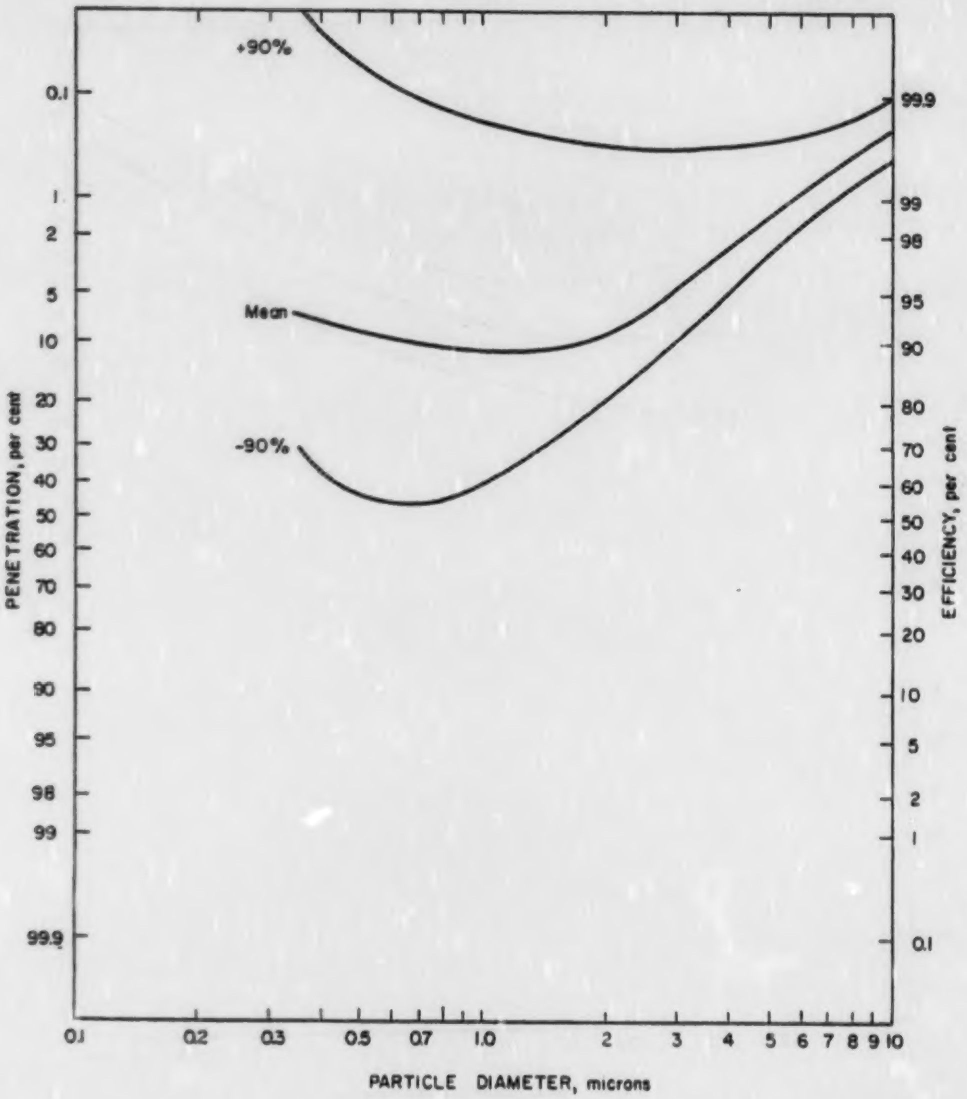

Figure 16. Efficiency versus particle diameter for December 18 (low sulfur coal with water injection).

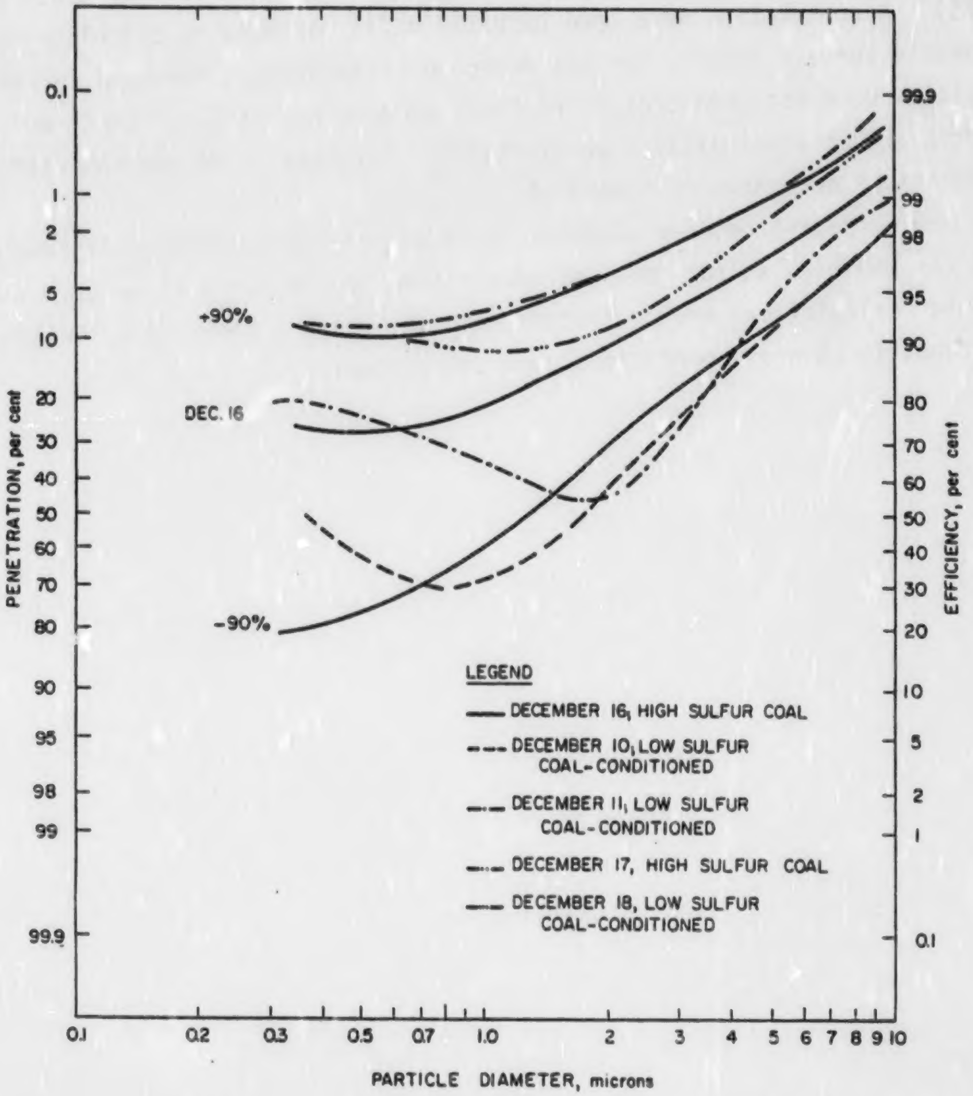

Figure 17. Efficiency versus particle diameter (all tests with ± 90% confidence).

Cragle (1976) reports that the use of LPA 402A at Montour reduced particulate emissions by a factor of about 5. Such a reduction in emissions is consistent with the change in dust resistivity reported here when LPA 402A was injected.

The performance of the electrostatic precipitator at Montour was modeled using the electrostatic precipitator computer model described by Gooch et al. (1975). A correlation developed by Hall (1971) was used to calculate the allowable current density for the measured resistivity. Measured current densities were not used because of their uncertainty (± 33 percent) and the inertia of the electrostatic precipitator. The results of the computer model calculations are shown in Figure 18.

The agreement between computer calculations and measured efficiencies is good for the high sulfur coal and conditioned low sulfur coal tests. The computer calculations are consistent with the results reported by Cragle (1976) for conditioned and unconditioned low sulfur coal.

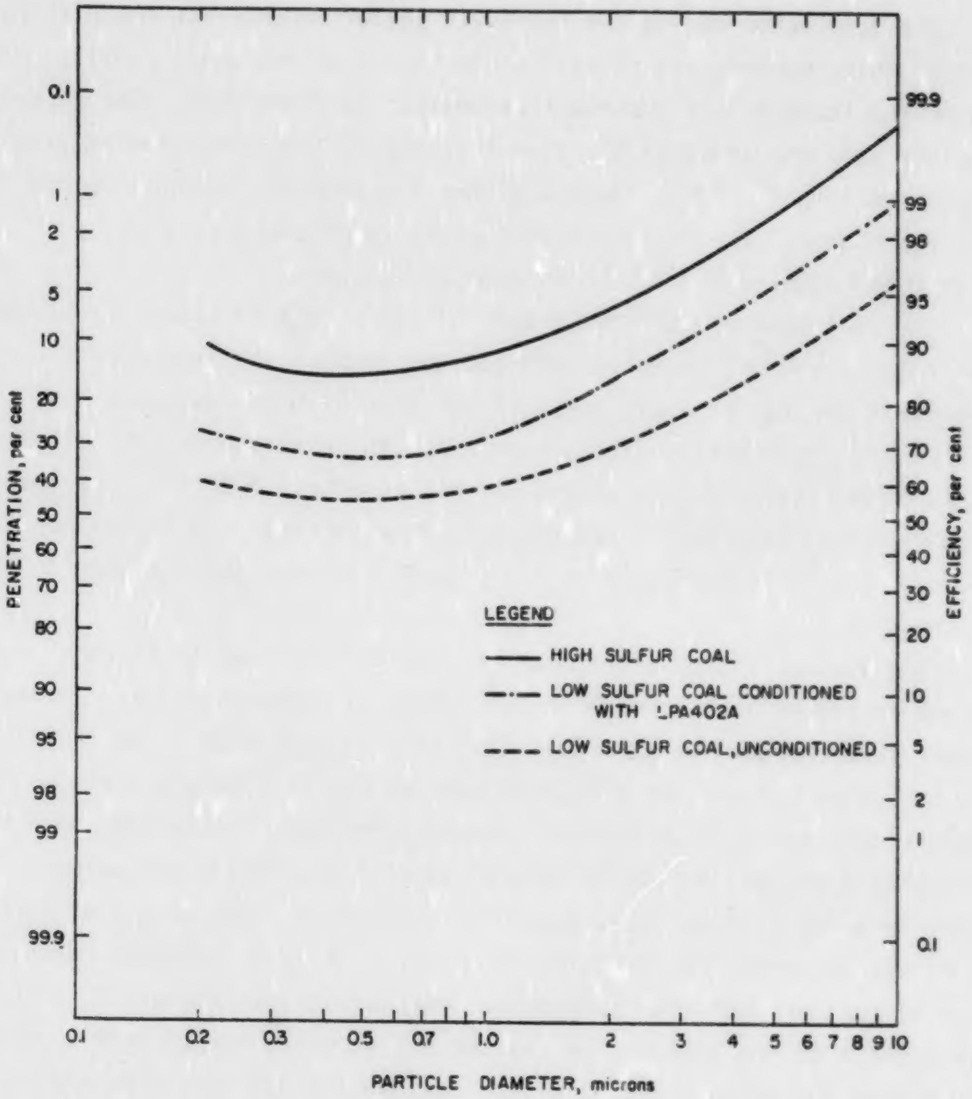

Figure 18. Efficiency predicted by ESP computer model as a function of particle diameter for Montour.

SECTION 5

RECOMMENDATIONS FOR FUTURE TESTS

The data taken during the tests at Montour demonstrate the difficulties of conducting experiments at full scale installations where complete control and/or knowledge of all important parameters is impossible. The experimental problems are compounded by the slow response of the electrostatic precipitator to changes in ash resistivity and by the low precision of many of the measurement techniques. The following discussion is offered as guidance for future experiments similar to those conducted at Montour.

The fact that electrostatic precipitators respond slowly to changes in ash resistivity must be taken into account in planning experiments involving changes in ash resistivity; e.g., change from high to low sulfur coal (or use of conditioning agents). The schedule for the experiments must allow several days of electrostatic precipitator operation after conditions are changed before testing can begin. Secondary voltage-current data and/or continuous in-stack light transmittance data are useful for determining when to start testing.

The variability of plant operating conditions (due to factors such as change in boiler load, change in coal chemical composition, and ambient temperature changes) is extremely difficult to deal with. The inertia of the system and the immobility of some of the instruments used to make measurements make it impractical to use randomized experimental design.

Once equipment is set up to make inlet measurements for example, half a day to a day must be spent obtaining inlet data. The danger of such a procedure is demonstrated by the results of the sulfur dioxide measurements made at Montour when high sulfur coal was burned. It appears that the sulfur content of the coal on the day the outlet measurements were made was slightly lower than the sulfur content of the coal on the day the inlet measurements were made. The result of the change in coal sulfur content is an apparent removal of sulfur dioxide by the electrostatic precipitator.

A similar difference in coal sulfur content for the two low sulfur coals burned at Montour may be responsible for part of the difference on the sulfur trioxide data for the conditioned and unconditioned tests.

Simultaneous inlet and outlet measurements may help overcome some of the problems due to source variability.

For studies of conditioning agents it may be necessary to conduct one set of experiments to determine the effect of the conditioning agent on the electrostatic precipitator and a separate set of experiments to determine the impact of conditioning on gaseous emissions. An experimental design using randomized treatments might be feasible for the experiments on gaseous emissions.

The electrostatic precipitator computer model, Gooch et al. (1975), is a useful tool for dealing with some of the problems caused by source variability and system inertia. For example, the computer model can be used to estimate what will happen if sufficient time is available for the electrostatic precipitator to reach steady-state operation.

Secondary voltage-current data for all TR sets are essential for electrostatic precipitator evaluations.

The measurement techniques for many of the emissions of interest--for example, sulfur trioxide, ammonia, and particle size distribution--lack adequate precision when used in the field. Large amounts of data are required to statistically examine field test data. This fact must be kept in mind when a test plan is developed. The amount of data required for each test condition should be estimated from a knowledge of the precision of the measurement techniques and an estimate of the change in the quantity being measured due to change in operating conditions. If the time required for obtaining the required data is excessive, low levels of statistical confidence may have to be accepted.

SECTION 6

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3. Gooch, J. P., McDonald, J.R., and Oglesby, S. A Mathematical Model of Electrostatic Precipitation. EPA Report EPA-650/2-75-037, NTIS PB 246-188/AS. 1975

4. Hall, H.J., "Trends in Electrical Energization of Electrostatic Precipitators". Proceedings of the Electrostatic Precipitator Symposium, February 23-25, 1971. Birmingham, Alabama.

July 1976

APPENDIX A

EFFECT OF FLYASH CONDITIONING AGENT ON COAL-FIRED POWER PLANT EMISSIONS

by

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DISCLAIMER

This report has been reviewed by the Process Measurements Branch, Industrial Processes Division, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

The gaseous and particulate emissions from a coal fired power plant were studied to investigate the environmental effects of a chemical flyash conditioning agent. Low sulfur coal was burned, and the emission sampled, with and without chemical addition. High sulfur coal was burned without chemical addition. Sulfur oxides, ammonia, and organics concentrations were determined during the test program, and the flyash resistivity and precipitator removal efficiency were measured.

Mean SO_2 concentrations varied from 663 ppm for low sulfur, unconditioned (LS, UN) ash to 1141 ppm for the high sulfur coal (HS, UN). Low sulfur coal with conditioner (LS, C) yielded a mean of 879 ppm SO_2. The SO_3 concentration for LS, C and HS, UN cases averaged 29 ppm, while the LS, UN coal produced a mean SO_3 concentration of 16 ppm.

Ammonia was detected only during the LS, C run, and was apparently a decomposition product of the conditioner.

The organic samples were quantitatively analyzed only for diethylnitrosamine, and none was found by a procedure with a lower detection limit of about 5 ppt. A Level I analysis was also conducted.

Flyash resistivity measurements were made and, at constant temperature, the LS, C ash had a resistivity 60 percent lower than did the LS, UN ash, and generally comparable to the HS, UN ash resistivity. Particulate removal efficiency measurements, however, indicated that the LS, UN and HS, UN ashes were removed to about the same high efficiency, while the LS, C ash was less efficiently removed. A precipitator "inertia" effect, improving the LS, UN results, is suggested as a possible reason for this anomaly.

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Battelle Columbus Laboratories performed the organic vapor analyses for the Montour tests.

Douglas VanOsdell of the Research Triangle Institute provided editorial assistance in the preparation of this report.

SECTION A-1

INTRODUCTION

The Particulate Technology Branch (PATB) of IERL-RTP requested in November 1975 that the Process Measurements Branch (PMB) conduct a study of the effects of a chemical flyash conditioning agent upon the effluent characteristics of an ESP-controlled coal-fired power plant. Arrangements were made with the Pennsylvania Power and Light Company to test such a scheme at their Montour Station during December 1975.

The goals of the program as agreed to by PATB and PMB were:

1) Ascertain the gaseous effluent content for both additive and non-additive conditions. This was to include SO_2 and SO_3, NH_3, and organics (specifically nitrosamines).
2) Measure the flyash resistivity.
3) Determine the flyash particle size distribution.

Because of the manpower limitations, no effort was to be made to obtain mass loading information. Through a PATB contract, Southern Research Institute personnel were provided to assist in gathering the data.

SECTION A-2

EXPERIMENTAL

2.1 TEST SCHEDULE

The Montour test program was conducted as described in Table A-1. At the onset of the program, December 10 and 11, low sulfur coal was burned and the LPA 402A was injected at 95 l/hr. During the weekend, and through December 17, high sulfur coal was burned without injection of any conditioner. On December 18, 1975, the plant was switched back to low sulfur coal, but the additive was not injected. Water was injected as a conditioner at 95 l/hr during this low sulfur run. The original test plan called for continuous low sulfur coal burning from the beginning of the test until after the low sulfur coal tests were completed. A low sulfur coal train was derailed, however, and the Montour plant was forced to go to high sulfur coal over the weekend and then back to low sulfur coal to complete the test.

TABLE A-1. TEST SCHEDULE (1975)

December 8 and 9	Arrive at plant and set up.
December 10 and 11	Full load tests using low sulfur coal, conditioner LPA 402A injected.
December 12	No tests; crew returns to Research Triangle Park, N.C.
December 13 and 14	Weekend, no tests.
December 15	Crew returns to plant.
December 16	Full load tests using high sulfur coal. No additive injection.
December 17	Full load tests using high sulfur coal. No additive.
December 18	Full load tests using low sulfur coal, water injected.

The precipitator controlling a single boiler was tested on both the inlet and outlet sides. The additive was injected upstream of the inlet port. The precipitator had a total plate area of 42,808.3 m^2 (460,800 ft^2), with 2675.5 m^2 (28,800 ft^2) supplied by each power supply.

Table A-2 presents the test plan for Montour. The 5 cfm cyclone train was not used due to damaged connector threads. The remainder of the plan was followed.

TABLE A-2. TEST PLAN

Test	Location	No. Per Day	Time Per Test
Dust Resistivity SRI Probe	ESP Inlet	3	2-3 hrs
Particle Size Distribution using Brink Impactors	ESP Inlet	4	1/2-1 hr
Particle Size Distribution using Andersen Impactors and 5 cfm Cyclone Train	ESP Outlet	4	1-2 hrs
SO_2/SO_3 and NH_3	ESP Inlet & Outlet	2	4
Organics	ESP Inlet & Outlet	2	4
Opacity	ESP Inlet EPA Instrument		Continuous
Opacity	ESP Outlet PP&L Instrument		Continuous

2.2 SULFUR OXIDES

Description of Test Method

Sulfur oxides concentrations during the Montour test program were determined by the IPA-Thorin titration method. The method was originally developed by Shell Development Co. and has been adapted by EPA. It is based on absorption of the sulfur oxides in 80 percent isopropanol (IPA) and 3 percent hydrogen peroxide (H_2O_2), and subsequent titration for sulfate ion.

Figure A-1 is a schematic of the apparatus used at Montour. Glass wool inside the duct filters out particulate. The temperature of the probe was kept at approximately 121°C (250°F) in order to prevent condensation within the probe. The first absorber contained 30 milliliters of 80 percent IPA. The alcohol was used to extract SO_3 and prevent oxidation of the SO_2. The absorbers used were modified Lamp sulfur absorbers called Shell bubblers. Alyea and Backstrom[1], and Flint[2] have confirmed the effectiveness of IPA as an inhibitor of SO_2 oxidation. Gaseous SO_3 is imperfectly extracted in the IPA and forms a fine sulfuric acid mist. A disengagement device must be used to prevent carryover of the mist into the next absorber. A bulbous disengagement volume was used in the Montour test program. The works of Flint[2], Shell[3], and Matty and Diehl[4] have confirmed that SO_3 can be quantitatively extracted using this procedure.

Gaseous SO_2 is absorbed in the IPA to some extent, and it is necessary to purge air or nitrogen through the IPA solution to strip the SO_2 out of the IPA. Shell[3] has shown that 15 minutes is adequate to strip out all of the dissolved SO_2 when using Lamp sulfur absorbers. Approximately 15 minutes of air purge was used during the Montour tests.

The second and third bubblers in the train contained a 3 percent aqueous solution of hydrogen peroxide to extract the SO_2 from the gas stream. Shell Development Co.[3] has shown that 100 percent of the SO_2 can be recovered by using two H_2O_2 absorbers in series.

Downstream of the second H_2O_2 absorber a drying column was used to dry the gas before it entered the dry gas meter. Temperature and pressure measurements were made in conjunction with the flowrate measurement.

After the test program was completed, the concentration of sulfate in the absorbers was determined by titration with a barium perchlorate solution to the Thorin endpoint. The first absorber solution and the disengagement impinger were washed together in order to collect all of the SO_3 sulfate, then titrated. The SO_2 concentration was determined by titration of the combined solution from the last two absorbers after addition of some IPA. The Thorin indicator is active only in an alcohol solution. A blank was carried throughout the titration procedure each day. The IPA and H_2O_2 solutions were prepared fresh daily.

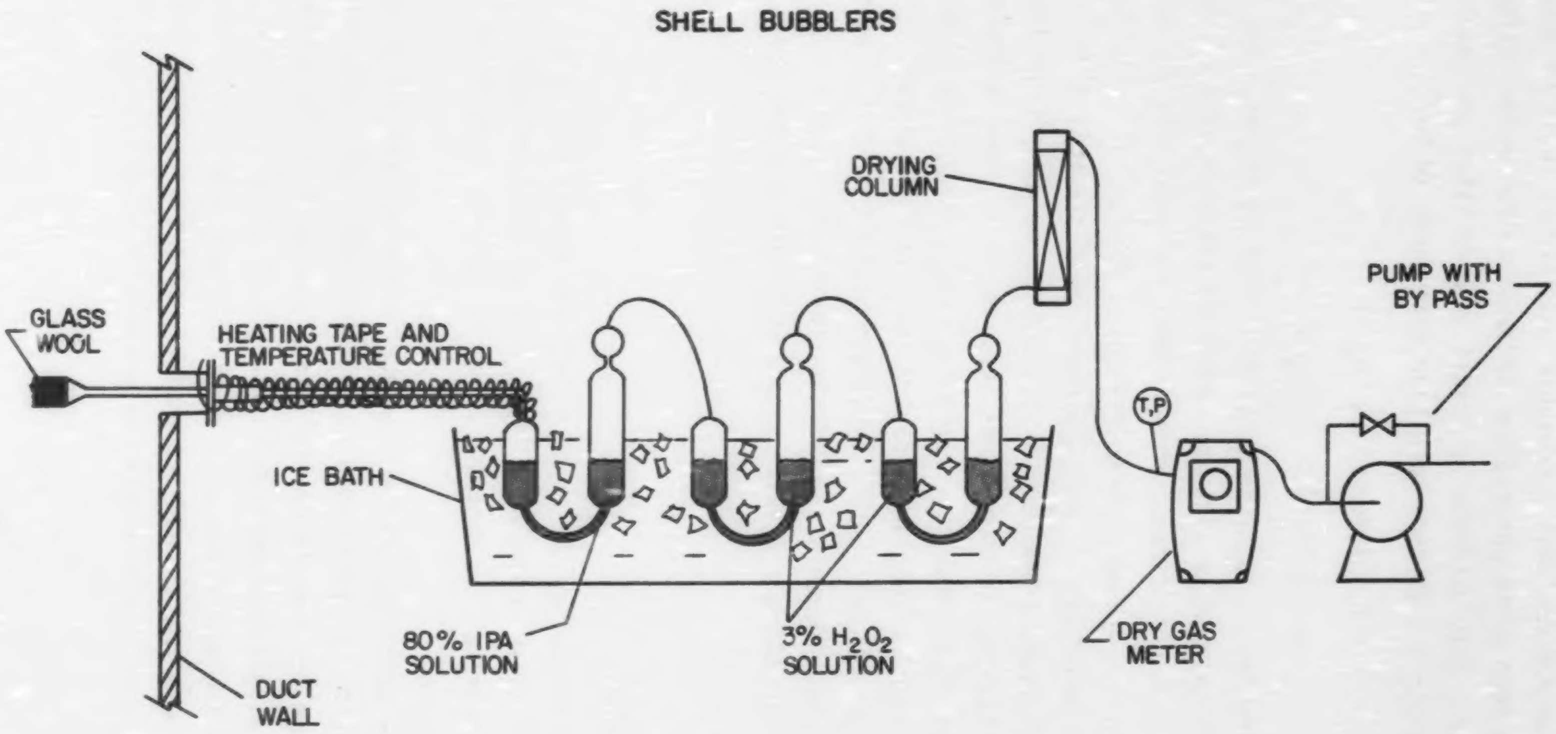

SHELL BUBBLERS
DRYING COLUMN
PUMP WITH BY PASS
GLASS WOOL
HEATING TAPE AND TEMPERATURE CONTROL
T,P
ICE BATH
80% IPA SOLUTION
3% H_2O_2 SOLUTION
DRY GAS METER
DUCT WALL

Figure A-1. Sulfur oxides sample train.

Quality of Measurement

Shell Development determined that acceptable sensitivity could be obtained over the range of 25 to 6000 parts per million of total sulfur oxides using the IPA-Thorin technique. This estimate was based on a 42 liter gas sample.[3]

Errors in the IPA-Thorin Titration have been determined to be:[5]

± 0.4 % for 25 μg SO_3/ml

± 4 % for 2.5 μg SO_3/ml

In other words, the titration is accurate to within ± 0.1 μg SO_3/ml. For 30 ppm of SO_3 in a 60 liter gas sample with the absorbent solution diluted to 250 ml and titrated, the solution would contain about 25 μg SO_3/ml, for an error of about 0.4 percent. The SO_3 concentration in the H_2O_2-IPA solution will be higher, and the error less. Absolute accuracy of the method has not been determined. However, comparison of the IPA-Thorin with other techniques (Seidman[6] and Fritz and Yamamura[7]) has shown no significant differences. The IPA-Thorin procedure is subject to some limitations. Errors may occur in high fluoride gas streams (fluoride concentration > sulfide concentration), if the filter is not used and particulate penetrates the probe or if condensation occurs in the probe. Ammonia and certain ammonia compounds are also said to interfere with the SO_3 determination, although this has not been quantified.[8]

2.3 AMMONIA

Description of Test Method

Ammonia concentration during the Montour test was determined by a modified Kjeldahl-Titrimetric Procedure. The procedure was developed by EPA personnel. It is based on the absorption of the ammonia in sulfuric acid followed by titration.

A schematic of the apparatus used at Montour to collect ammonia is shown in Figure A-2. Glass wool was again used to prevent particulate from entering the probe. Heating tape was used to control the temperature of the probe and the absorbers are midget impingers which contain 15 ml of 0.1 normal sulfuric acid. Two empty impingers were used as entrainment separators. A silica gel column was used to dry the gas and temperature and pressure measurements were made concurrently with the flow rate measurement.

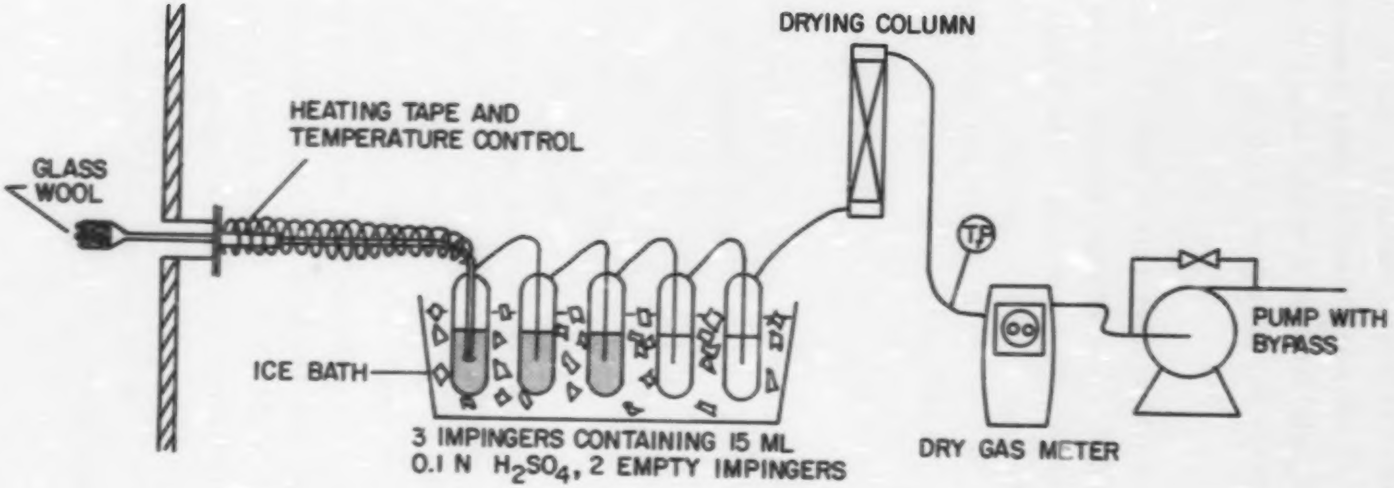

DRYING COLUMN
HEATING TAPE AND TEMPERATURE CONTROL
GLASS WOOL
TP
PUMP WITH BYPASS
ICE BATH
3 IMPINGERS CONTAINING 15 ML 0.1 N H_2SO_4, 2 EMPTY IMPINGERS
DRY GAS METER

Figure A-2. Ammonia sampling apparatus.

Discussion of Titration Method

After the gas sample had been passed through the absorbent solution, the contents of the impingers were combined. Free ammonia was distilled over into a flask containing boric acid and indicator solution (2:1 mixture of methyl red and methylene blue in 95 percent ethanol), where ammonia borate was formed. Titration with 0.02 N H_2SO_4 yielded the acid equivalent to the distilled ammonia. The indicator change was from green to blue.

Quality of Measurement

EPA personnel have determined that this method of ammonia concentration determination has an accuracy of ± 2 percent between 10 and 500 ppm for a 20 liter sample. The precision is about the same. The procedure has not been used above 500 ppm, and its upper limit is unknown.

A blank was used to check on the titration and correction was applied to the results if needed. A blank was run each day, as the solutions were made up fresh daily.

2.4 ORGANIC VAPORS

The composition of organic vapors which might be present in the flue gas was of interest because of possible undesirable decomposition products from the injected additive. Organic vapors frequently occur in flue gases in very low concentrations and it is often necessary to use concentrating techniques to make accurate measurements. Absorption of the organics from a large gas volume onto a polymer medium, followed by desorption into a smaller volume, is a commonly used method. During the Montour tests, about 1415 liters (50 scf) of gas was passed through the absorbent and the organics were desorbed into about 120 ml of pentane. The sample train used in the Montour tests is shown as Figure A-3. The gas sample was collected by a heated probe which was kept constant at about 70°C. The cyclone and filter were used to remove particulate from the stream, and the oven and heat exchanger maintained a constant gas temperature of about 60°C. The particulate was not analyzed. The prepackaged cartridge contained Tenax GC [a polymer of 2,6-(diphenylpara-phenylene)oxide] as the absorbent. The remainder of the train consisted of a standard mass sampling train. Sulfur oxides were removed and the gas was dried prior to flowrate measurement.

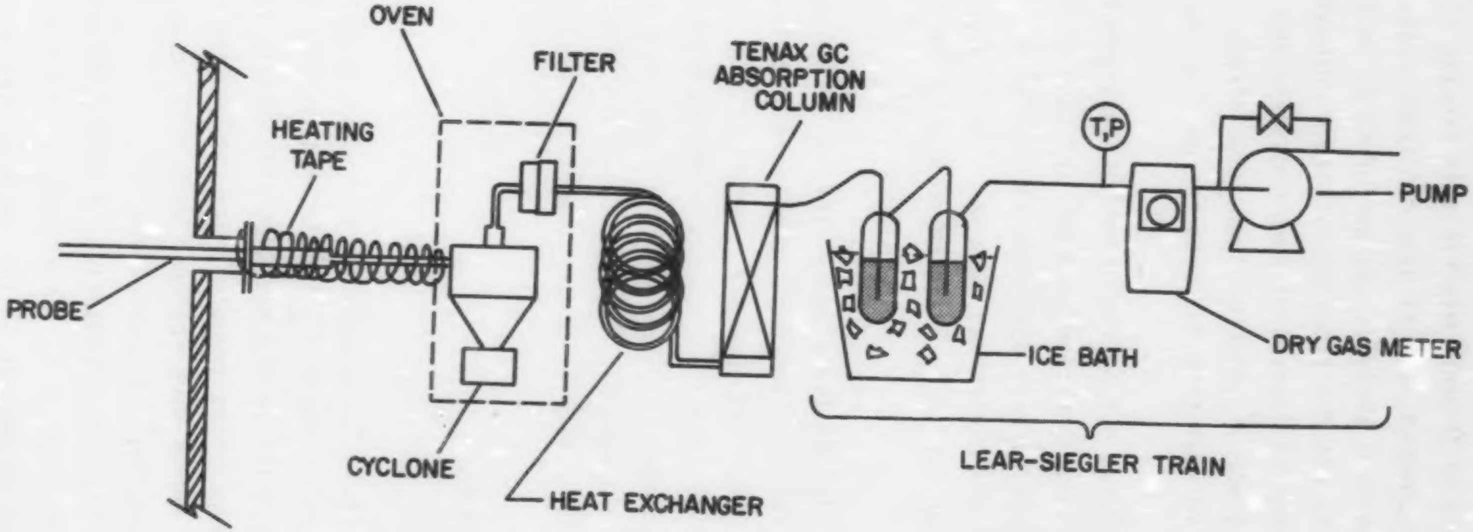

OVEN
FILTER
TENAX GC ABSORPTION COLUMN
HEATING TAPE
T,P
PUMP
PROBE
ICE BATH
DRY GAS METER
CYCLONE
HEAT EXCHANGER
LEAR-SIEGLER TRAIN

Figure A-3. Organic sampling apparatus.

The analysis of the organic samples was conducted as described in "Technical Manual for Analysis of Organic Materials in Process Streams."[9] The absorbed organics were recovered in a 24 hour continuous pentane extraction. Level I (semi-quantitative) analysis was performed on half of each extracted sample. Each sample was fractionated by liquid chromatography into eight fractions. The general classes of compounds expected in each fraction were known from previous work.[9] Fourier Transform Infrared Spectroscopy (FTIR) was used to achieve semi-quantitative data for each of the 40 individual fractions.

Further analysis was carried out on the unfractionated samples. Diethylamine was chosen as a likely decomposition product, and each of the samples was analyzed by gas chromatography/mass spectroscopy (GC/MS) for the amine.

The analysis procedures are elaborated upon in a letter report by P.W. Jones to Dr. L.D. Johnson, which is attached as Appendix A-A.

Quality of Measurement

The sensitivity of the FTIR analysis varies for the different fractions of the Level I analysis. Fraction 1 and 2 compounds are detected at around 1-10 μg while those in Fractions 3 through 8 are detected at 0.1 to 1 μg levels.

The GC/MS analysis used to detect and quantify diethylnitrosamine is both sensitive and precise. Recoveries of nitrosamine in processing were estimated at 80 percent. As explained in Appendix A-A, the detection limit for nitrosamine was around 5 μg, and for a 1400 l (50 scf) sample this is about 3 parts per trillion (ppt).

2.5 PARTICULATE SIZE MEASUREMENT

Description of Test Method

Cascade impactors, inertial sizing devices, were used to determine particulate size distributions at Montour. The Brink Impactor, a low sample rate device, was used on the inlet to the electrostatic precipitators and the Andersen Impactor, a high sample rate impactor, was used on the outlet. Normal isokinetic sampling procedures were followed with both impactors and they were operated to minimize scouring and overloading.[10]

A particulate sampling train representative of that used with the Andersen and the Brink is shown in Figure A-4. Each impactor was operated within the stack and the temperature of the gas in the impactor was measured by

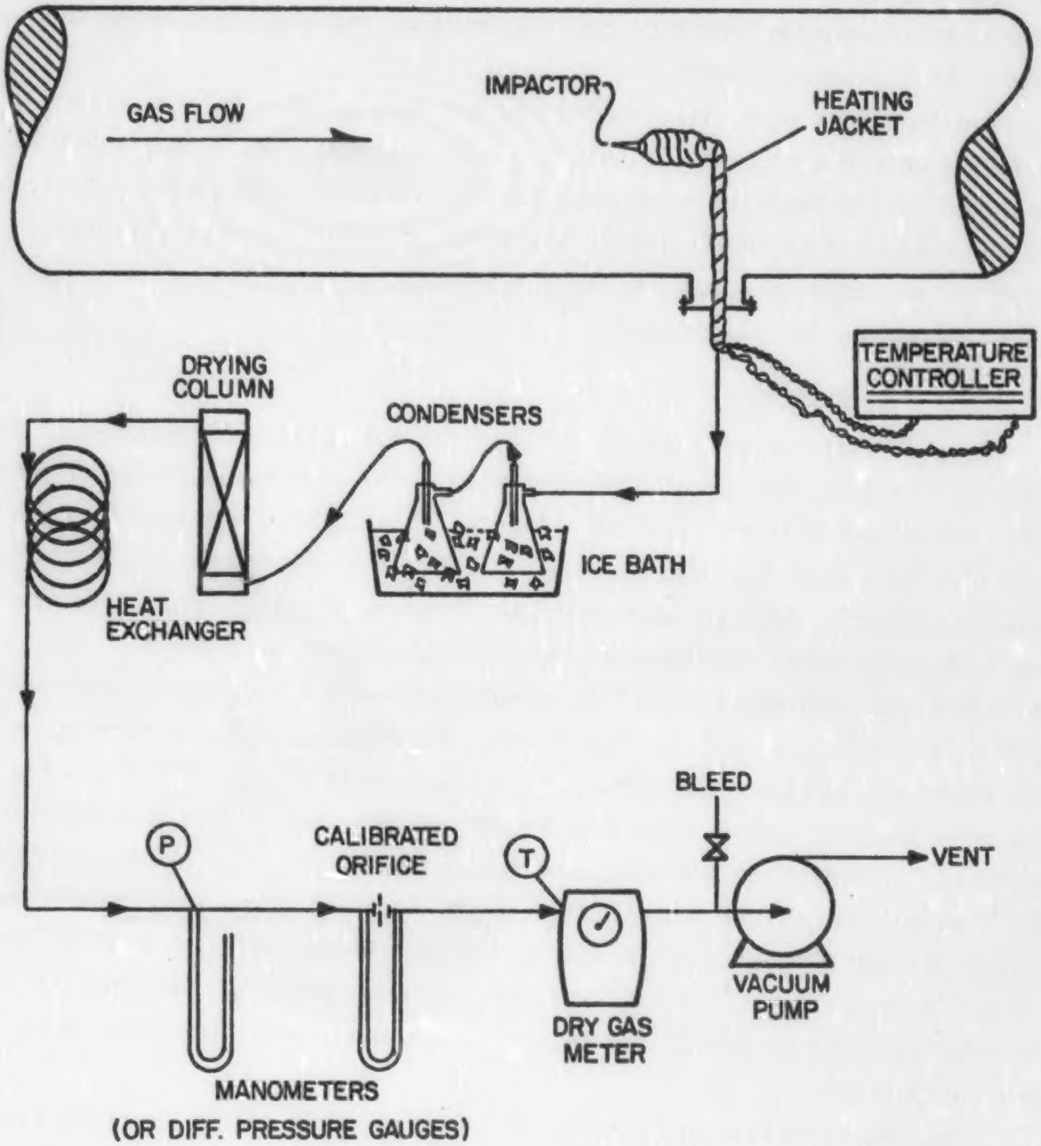

GAS FLOW
IMPACTOR
HEATING JACKET
TEMPERATURE CONTROLLER
DRYING COLUMN
CONDENSERS
ICE BATH
HEAT EXCHANGER
BLEED
P
CALIBRATED ORIFICE
T
VENT
VACUUM PUMP
DRY GAS METER
MANOMETERS
(OR DIFF. PRESSURE GAUGES)

Figure A-4. Impactor sampling train.

thermocouple. A heat exchanger was used to reduce temperature fluctuations during the sample period. The drying column of indicating silica gel dried the gas. Pressure and temperature measurements were made concurrently with the flowrate measurements. Dual flowrate instruments were used: an orifice meter with a manometer for flowrate measurements and a dry gas meter for volumetric flow measurements.

The impactors were disassembled and the mass of particulate on each stage was determined gravimetrically. Factory precut glass fiber substrates were used in the Andersen impactor. Foil substrates, coated with polyglycol grease, were used as substrates in the Brink impactor. A straightforward data reduction was used to determine the differential size distribution on both the inlet and outlet measurements.[10]

Quality of Measurement

Several steps were taken to increase the reliability of this data. The data were examined and unreliable data were eliminated as described in Appendix A-B. The weights of particulated collected on each stage during the impactor runs have also been included in Appendix A-B. The fiberglass substrates used with the Andersen impactor were preconditioned by in-situ exposure to the flue gas using procedures developed by the Southern Research Institute. This was to reduce the problem of anomalous weight gains which have been observed in some cases in SO_2 containing flue gases. Blanks were also run each day with the Andersen impactor. The stage weights were determined after operating the impactor on filtered flue gas, and the weight change on each stage was measured. If weight gains were observed on the stages, the average weight gain was determined and subtracted from the Andersen stage weights obtained during the day's runs. More specific information on the blank runs is presented in Appendix A-B. Blanks were not run with the Brink impactor, as the impactor was upright during the test and experience indicated they would be unnecessary.

The data reduction used the Southern Research Institute computer program which is based on a fixed impaction parameter of 0.145 for round jet impactors.

2.6 FLYASH RESISTIVITY

Measurement Technique

The resistivity of the flyash was measured using an in-situ point-to-plane resistivity probe, and the reported results were obtained using the parallel disc method. Figure A-5 shows a probe of this type. The point-to-plane in-situ probe simulates dust collection as it occurs in an ESP. The data derived from point-to-plane probes is, therefore, thought to be more relevant to precipitator performance than is data derived from mechanically collected dust.

The probe was inserted in the duct and allowed to come to thermal equilibrium prior to taking a reading. The parallel disc method requires that a layer of dust (usually about 1 mm thick) be collected on the collection surface. The thickness of this layer was determined in-situ by lowering the upper disc until it just contacted the dust. With the upper disc in position, the voltage drop across the two surfaces was increased until the dust layer broke down electrically and sparkover occurred. From knowledge of the geometry of the surfaces and the voltage and current just prior to sparkover, the flyash resistivity was calculated.

Quality of Measurement

Flyash resistivity measurements as made at Montour have a precision of around ± 30 percent. This has been the precision achieved by Southern Research Institute personnel on similar tests and during this test program. The absolute accuracy of the data is not known, if indeed there is an absolute measurement. The measurement must be made indirectly, and is affected by the method of depositing the dust, of determining the thickness of the layer, by coal, by temperature, and boiler variables. The usefulness of the data is in its application to ESP design and performance, based on experience with similar tests.

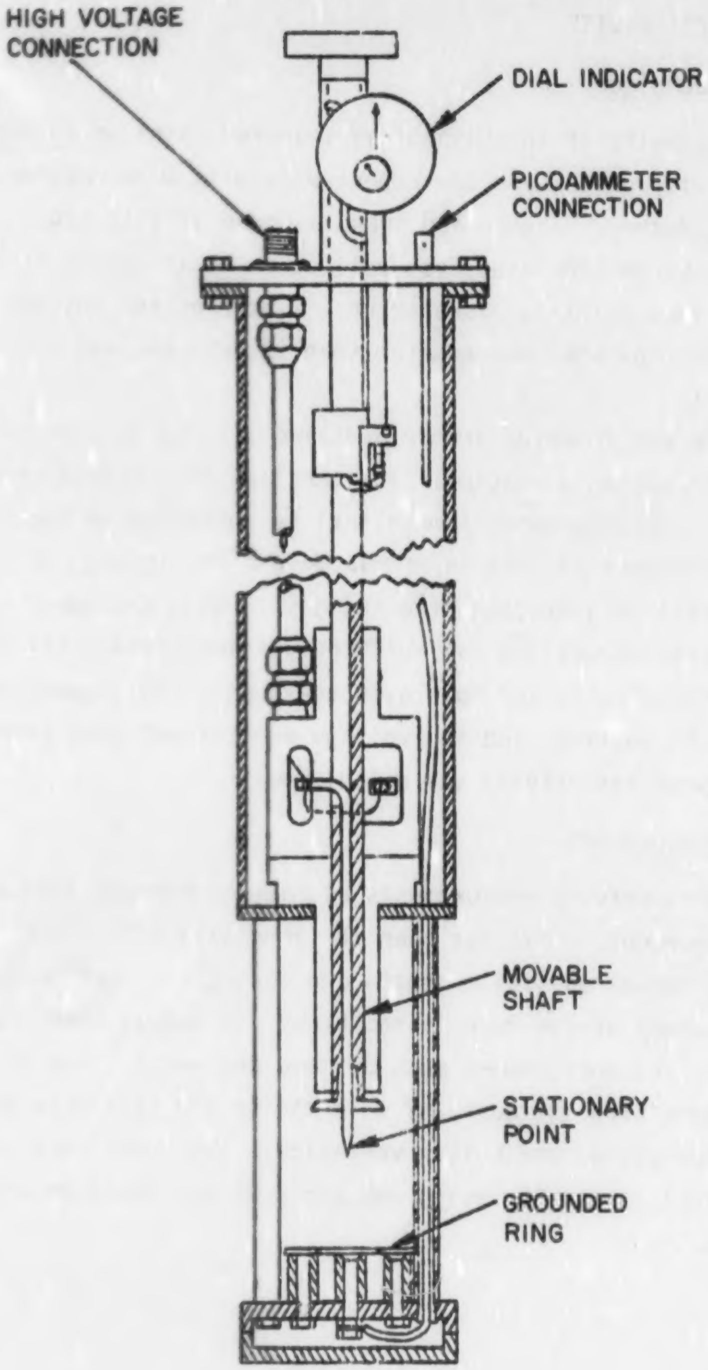

HIGH VOLTAGE CONNECTION
DIAL INDICATOR
PICOAMMETER CONNECTION
MOVABLE SHAFT
STATIONARY POINT
GROUNDED RING

Figure A-5. Point-to-plane flyash resistivity probe.[11]

SECTION A-3

RESULTS

3.1 SULFUR OXIDES

Montour Data

The sulfur oxides data taken during the LPA 402A injection are presented in Table A-3. The average SO_2 concentration was 879 ppm and the mean SO_3 concentration was 29 ppm. Low sulfur coal was being burned in the boiler while 95 l/hr of the additive was being injected. Data taken while burning high sulfur coal are presented in Table A-4. The mean concentrations for SO_2 and SO_3 were 1141 ppm and 23 ppm, respectively. Nothing was injected during this period. Table A-5 presents data on low sulfur coal with water injection.

Coal from the same seam was burned during both low sulfur coal runs, and it may be significant that the flue gas during water injection is considerably lower in sulfur oxides concentration. The plant was operating at about 8 percent greater output during the water injection runs.

As indicated in Tables A-3, A-4, and A-5, several of the SO_x data points were rejected as spurious values. A data point was rejected if it fell outside of the 90 percent confidence limits of the remainder of the data. The confidence limits were calculated about the mean as a multiple of the standard deviation. Based on the number of data points, "t-values" were used as the multiplying factor for the standard deviation.[12] This procedure is somewhat misleading, as it implicitly assumes that all the variation is random measurement error. In the case of power plant flue gas, boiler variation may impose additional variability on the data which is not error. With this limitation in mind, the procedure is still useful during periods of fairly constant boiler operation, as was apparently the case during the Montour tests. For the same reason, caution must be exercised when evaluating all of the statistical treatments of these data.

TABLE A-3. SULFUR OXIDES CONCENTRATION AT MONTOUR STEAM POWER PLANT LOW SULFUR COAL, FLYASH CONDITIONED WITH 95 l/hr LPA 402A

Sample	Location	Date & Time	PPM SO_2	PPM SO_3	PPM Total SO_x
1	Outlet	12/10/75 1000	856.0	28.2	884
2	Outlet	12/10/75 1030	873.4	6.1	879
3	Outlet	12/10/75 1035	875.5	50.0	926
4	Outlet	12/10/75 1050	826.5	24.5	851
5	Outlet	12/10/75 1100	700.8[a]	14.6	---
6	Outlet	12/10/75 1120	920.4	56.8	977
OUTLET			$\bar{X}$ = 870.4 σ = 34.2 CV = 4%	$\bar{X}$ = 30.0 σ = 19.8 CV = 66 %	903
17	Inlet	12/11/75 1105	957.0	38.1	995
18	Inlet	12/11/75 1120	857.1	29.0	886
19	Inlet	12/11/75 1130	1088.1[a]	31.3	---
20	Inlet	12/11/75 1140	862.5	18.2	881
21	Inlet	12/11/75	883.9	19.5	903
INLET			$\bar{X}$ = 890.1 σ = 46.1 CV = 5.2%	$\bar{X}$ = 27.2 σ = 8.35 CV = 30.7%	916
OVERALL AVERAGE			879	28.8	909

---

[a] Value rejected as spurious. Outside of 90% confidence limit. Mean ($\bar{X}$), standard deviation (σ), and coefficient of variation (CV) do not include this point.

TABLE A-4. SULFUR OXIDES CONCENTRATION AT MONTOUR STEAM PLANT HIGH SULFUR COAL, NO ADDITIVE INJECTION

Sample	Location	Date & Time	PPM SO_2	PPM SO_3	PPM Total SO_x
25	Inlet	12/16/75 1030	1261.9	13.3	1275
26	Inlet	12/16/75 1050	1444.2	12.4	1457
27	Inlet	12/16/75 1105	1373.3	32.7	1406
28	Inlet	12/16/75 1120	1281.4	56.8[a]	---
INLET			$\overline{X}$ = 1340 σ = 84.6 CV = 6.3%	$\overline{X}$ = 19.5 σ = 11.5 CV = 59%	1379
29	Outlet	12/16/75 1400	926.1	10.7	937
30	Outlet	12/16/75 1420	970.9	28.2	999
31	Outlet	12/16/75 1430	769.7	34.5	804
32	Outlet	12/16/75 1440	1100.8	28.9	1130
OUTLET			$\overline{X}$ = 942 σ = 136.6 CV = 14.5%	$\overline{X}$ = 25.6 σ = 10.3 CV = 40.3%	968
OVERALL AVERAGE			1141	23	1164

[a] Value rejected as spurious. Outside of 90% confidence limit. Mean ($\overline{X}$), standard deviation (σ), and coefficient of variation (CV) do not include this point.

TABLE A-5. SULFUR OXIDES CONCENTRATION AT MONTOUR STEAM PLANT LOW SULFUR COAL, 95 l/hr WATER INJECTION

Sample	Location	Date & Time	PPM SO_2	PPM SO_3	PPM Total SO_x
41	Outlet	12/18/75 1345	574.2	8.8	583
42	Outlet	12/18/75 1400	674.4	17.4	692
43	Outlet	12/18/75 1420	683.6	21.9	706
OUTLET			$\overline{X}$ = 644 σ = 60.7 CV = 9.4%	$\overline{X}$ = 16.2 σ = 6.7 CV = 41.5%	660
48	Inlet	12/18/75 1540	872.8	19.5	893
49	Inlet	12/18/75 1615	656.5	56.7[a]	---
50	Inlet	12/18/75 1630	518.9	12.4	531
INLET			$\overline{X}$ = 683 σ = 178.4 CV = 26.1%	$\overline{X}$ = 16.0 σ = 5.0 CV = 31.5%	712
OVERALL AVERAGE			663	16	679

[a] Value rejected as spurious. Outside of 90% confidence limits. Mean ($\overline{X}$), standard deviation (σ), and coefficient of variation (CV) do not include this point.

Comparison of Montour to Other Power Plants

Table A-6 presents the results of a comparison of the Montour sulfur oxides data with that taken at other power plants. The Montour data consists of from three to six point averages, while the other data are averaged from at least eight points. The variability in the SO_2 measurements at Montour is consistent with that found at other locations. The coefficients of variation of the SO_3 measurements are, in some cases, larger than the norm. The small number of measurements in the Montour sample probably accounts for some of this variation.

3.2 AMMONIA CONCENTRATIONS

The results of the ammonia concentration measurements are presented in Table A-7. Ammonia was detected only during the injection of LPA 402A. The reliability limit of the test procedure has been established as 10 ppm, and five of the samples in which ammonia was detected are below this limit. The conditioning agent apparently contained nitrogen which could decompose to ammonia.

3.3 ORGANICS

The organic samples collected on the Tenax cartridges were extracted, then fractionated according to the methods presented as Level I analysis in "Technical Manual for Analysis of Organic Materials in Process Streams."[9] The five samples were each divided into two parts. One part was reserved for further analysis, while the other was fractionated by liquid chromatography into eight fractions. The weight of material separated into each fraction is presented below.

Sample	Fraction Weight (g)							
	1	2	3	4	5	6	7	8
J1	0.00023	0.0011	0.00054	0.0068	0.00082	0.0057	0.0014	0.00006
J2	0.0024	0.00044	0.00054	0.0091	0.00084	0.0065	0.00009	0.00003
J3	0.00023	0.00018	0.00023	0.0060	0.00018	0.00048	0.00004	0.00008
J4	0.00018	0.000077	0.00013	0.0039	0.00021	0.00027	0.00003	0.00001
SW1	0.0014	0.0038	0.00047	0.0010	0.00047	0.0077	0.00001	0.000005

TABLE A-6. COMPARISON OF SULFUR OXIDES DATA FROM VARIOUS POWER PLANTS

Power Plant	SO_2 (ppm)	CV_{SO_2}	SO_3 (ppm)	CV_{SO_3}
PPL (Shemokan) March 1975	1700	6%	54.7	26%
PPL (Shemokan) March 1975	652	13%	40.2	26%
IPC (East Alton)	2339	13%	11.0	16%
WEPCO	1550	13%	16.3	28%
Shawnee	--	--	25.0	45%
Walden Research	--	--	29.0	28%
Averages	--	11%	--	28%
PPL (Montour)				
Low S, water injection				
Inlet	683	26%	16	32%
Outlet	644	10%	16	42%
Low S, LPA 402A injection				
Inlet	890	5%	27	31%
Outlet	870	4%	30	66%
High S, no injection				
Inlet	1340	6%	20	59%
Outlet	942	14%	26	40%

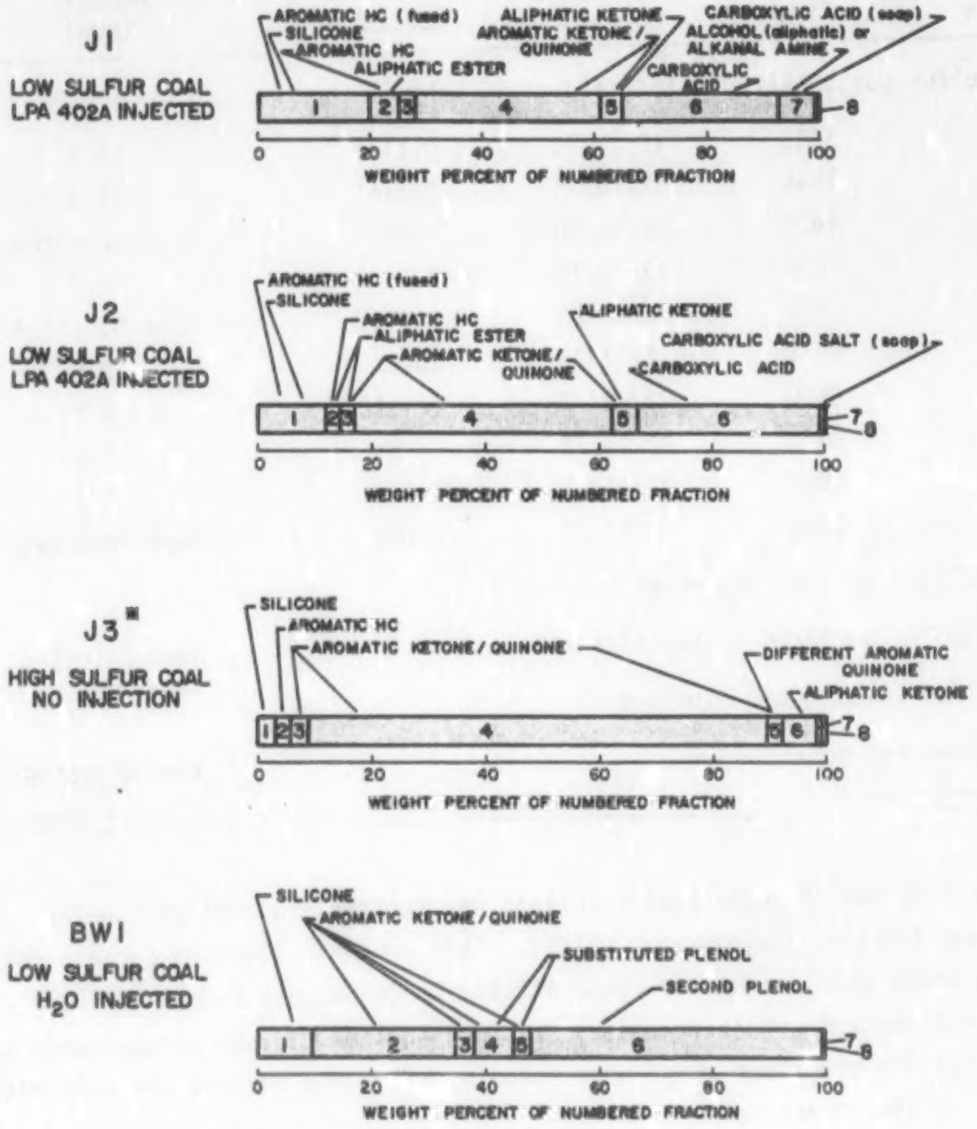
TABLE A-7. AMMONIA CONCENTRATION AT MONTOUR POWER PLANT

Sample	Time	Date	Location	Ammonia (ppm)
Low Sulfur Coal, LPA 402A Injected at 95 l/hr				
7	1535	12/10/75	Outlet	18.2
8	1545	12/10/75	Outlet	17.5
9	1600	12/10/75	Outlet	None Detected
10	1610	12/10/75	Outlet	4.7
11	1620	12/10/75	Outlet	None Detected
12	0915	12/11/75	Inlet	2.6
13	0930	12/11/75	Inlet	4.5
14	0940	12/11/75	Inlet	5.8
15	0950	12/11/75	Inlet	1.9
16	1000	12/11/75	Inlet	None Detected
High Sulfur Coal, No Injection				
Six samples on 12/16/75 and 12/17/75				None Detected
Low Sulfur Coal, Water Injected				
Eight samples on 12/18/75				None Detected

Each of the 40 individual fractions was further analyzed by Fourier Transform Infrared Spectroscopy (FTIR). This analysis detected certain material classes which were present in comparatively large amounts (< around 10-30 μg). Figure A-6 presents these results. The compounds or classes of compounds which are identified are those which were found by FTIR, and are not the only materials present in that fraction.

A quantitative analysis for nitrosamine was carried out on half of each of the original organic samples, Diethylnitrosamine was chosen as a likely decomposition product of the injected conditioner. No diethylnitrosamine was found in any of the samples; for the gas volumes which were collected, the nitrosamine composition must have been below about 2-5 parts per trillion.

Further discussion of the results is attached in Appendix A-A.



Notes: * SAMPLE J4 VERY SIMILAR TO SAMPLE J3. THE IDENTIFIED COMPOUNDS ARE NOT THE ONLY COMPOUNDS PRESENT IN A GIVEN FRACTION.

Figure A-6. Results of Level I organic analysis at Montour.

3.4 PARTICLE SIZE

Particle Size at Inlet to ESP

The differential size distributions calculated from Brink impactor data taken on the inlet side of the Montour ESP are presented in Figures A-7 through A-10. Figure A-10 is an average of the five days of testing, and the other figures are means for the indicated days. The 90 percent confidence limits for the data are also presented on these Figures. The 90 percent confidence range is small for the combined five days' data indicating consistency over a number of tests. Coal type and boiler variables have little apparent effect on the inlet particle size distributions.

Outlet Particle Size Distributions

The particulate data from the outlet side of the ESP, taken with an Andersen impactor, are presented in Figures A-11 through -13. The 90 percent confidence limits for the data have also been included on these figures. The scatter of the outlet data was considerable both within a given data set and from day to day. The size of the confidence ranges is an indication of the scatter within a data set, and Figure A-14 shows the day-to-day variation.

Fractional Efficiency

Estimates of fractional removal efficiency on each of the five days are presented in Figure A-15. The highest efficiency of removal was achieved on one day of high sulfur coal. Contrary to expectations, the low sulfur coal with water injection was controlled to nearly the same efficiency as the high sulfur coal, and considerably better than the conditioned ash was controlled. This result is inconsistent with the lowered flyash resistivity of the conditioned ash, which one would expect to lead to improved collection.

3.5 FLYASH RESISTIVITY

The flyash resistivity data taken at Montour is tabulated in Table A-8 and presented as a function of temperature and firing condition in Figure A-16. The data are consistent for resistivity measurements, even when ignoring the effect of temperature. Standard deviations and coefficients of variation for the data are also presented in Table A-8. Based on this data, the LPA

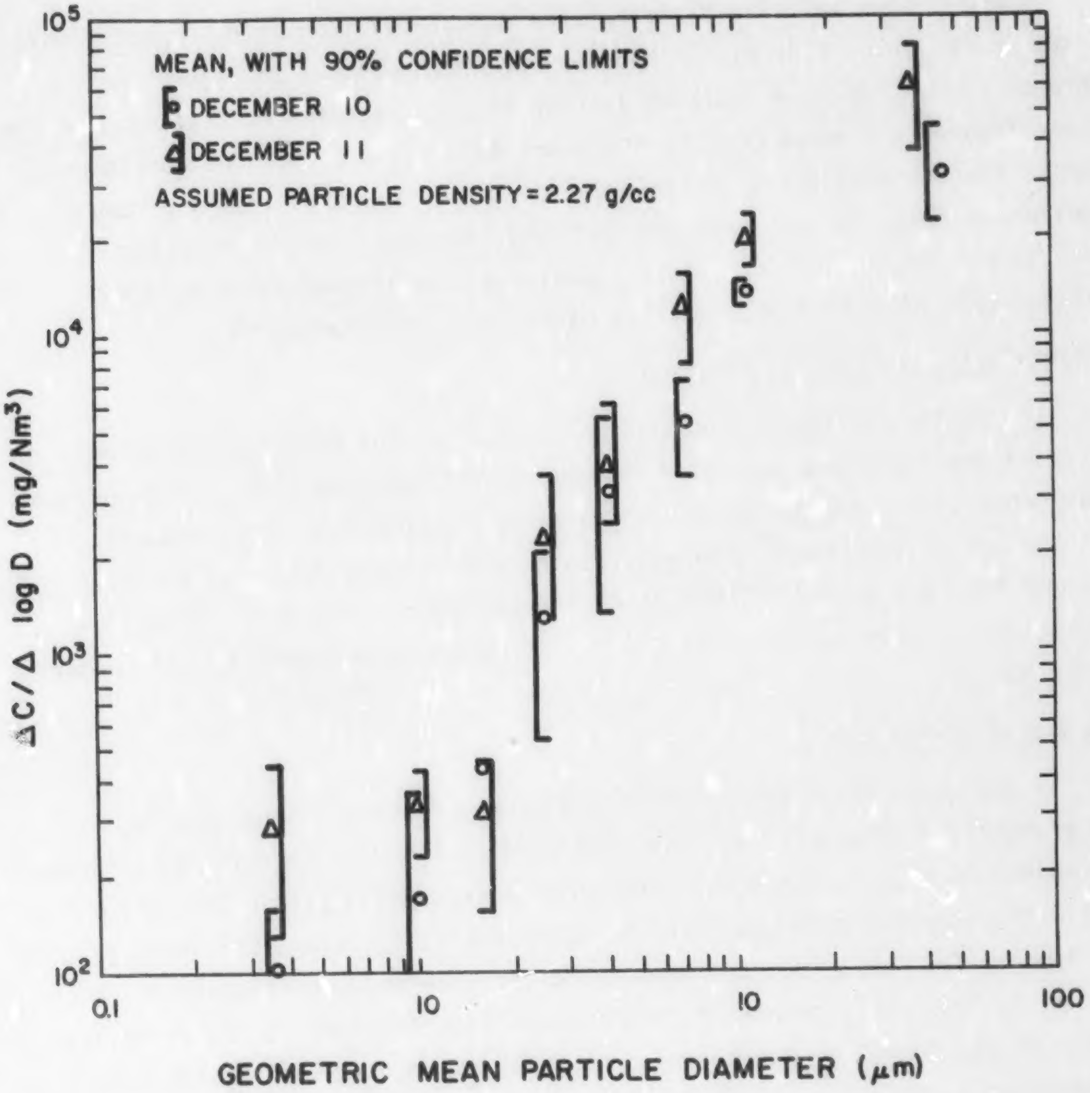


Figure A-7. Differential particle size distribution at inlet to ESP, Montour Plant, December 10 and 11, 1975; low sulfur coal, conditioner injected at 95 l/hr.

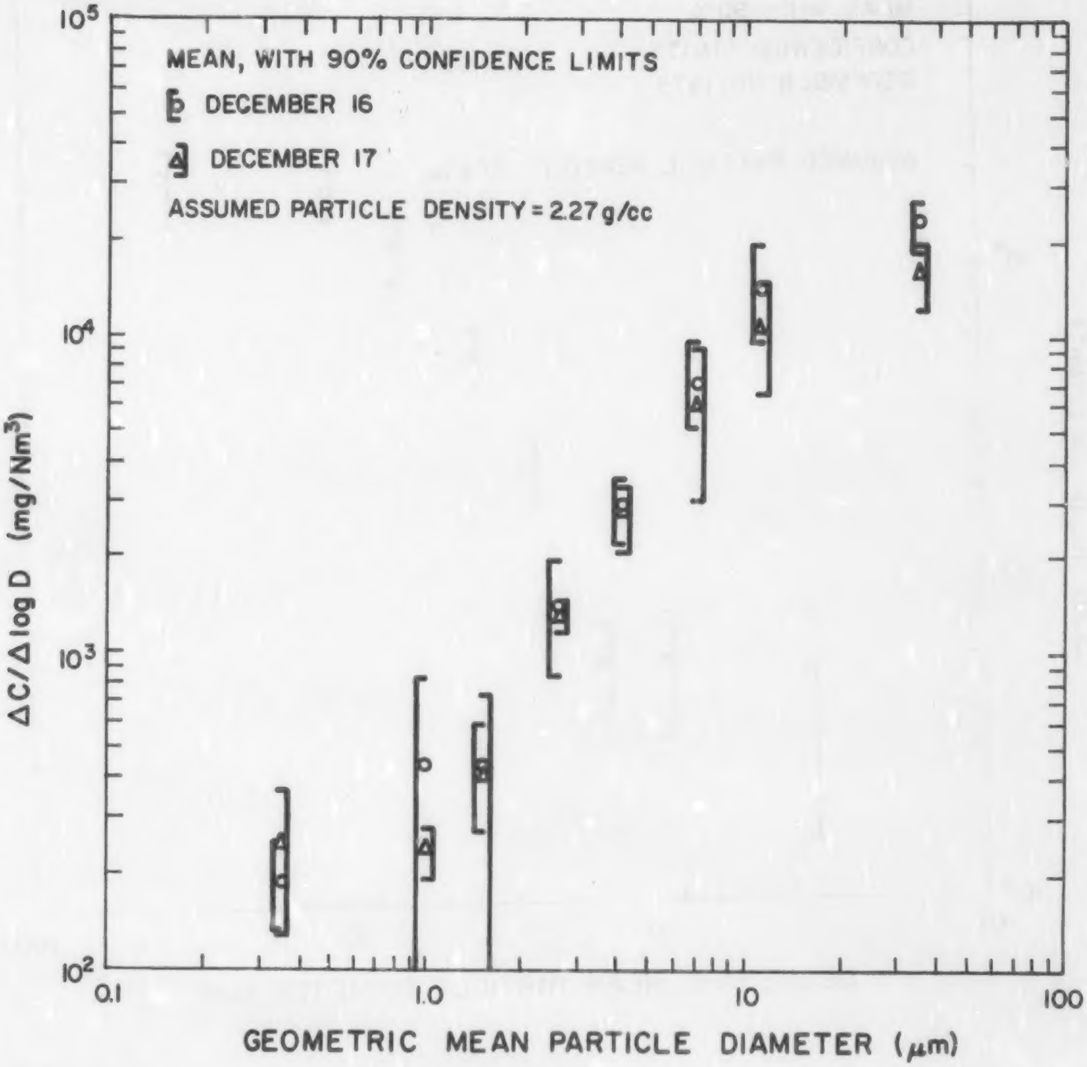


Figure A-8. Differential particle size distribution at inlet to ESP, Montour Plant, December 16 and 17, 1975; high sulfur coal, no conditioner.

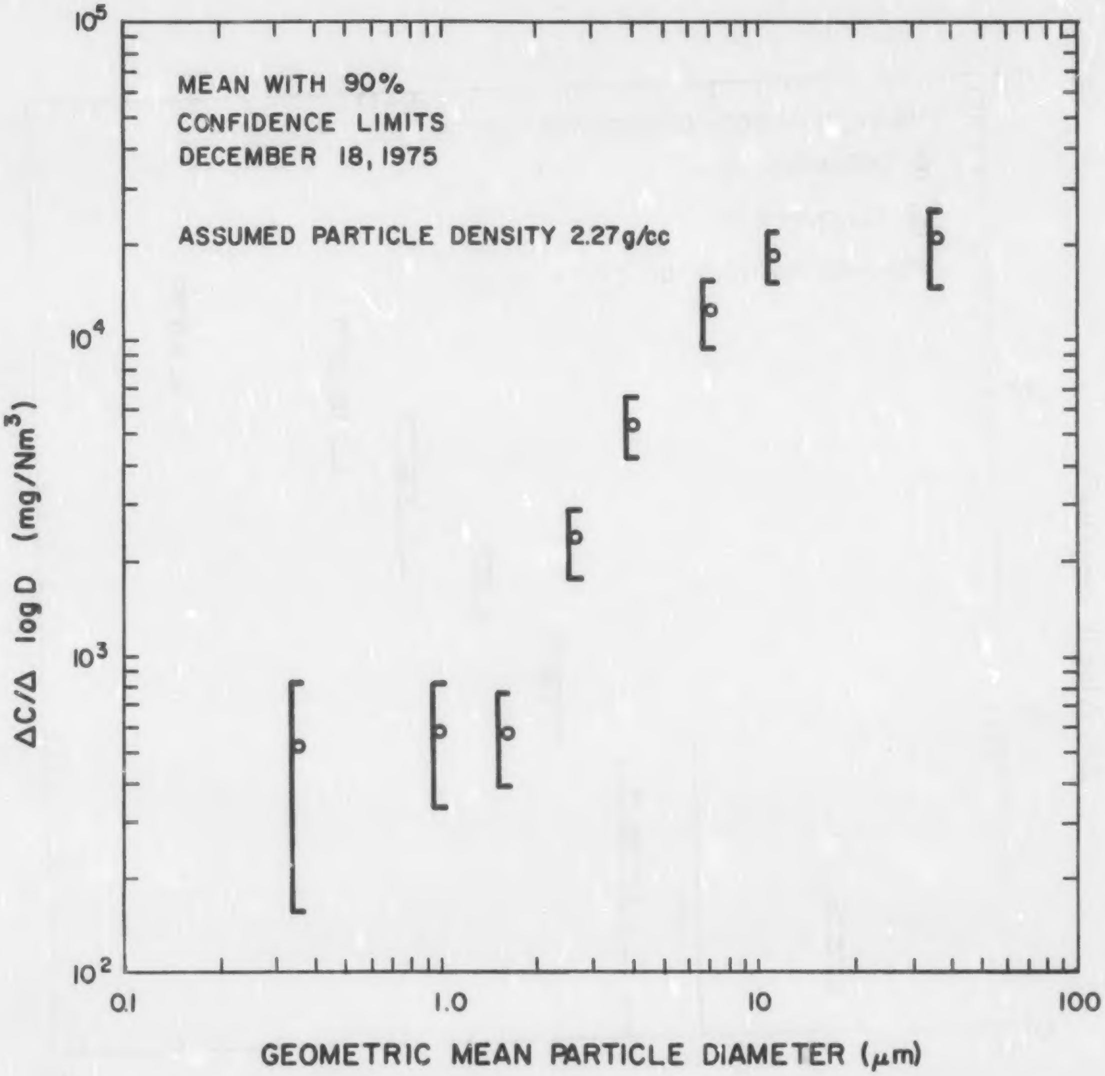


Figure A-9. Differential particle size distribution at inlet to ESP, Montour Plant, December 18, 1975; low sulfur coal, water injected at 95 l/hr.

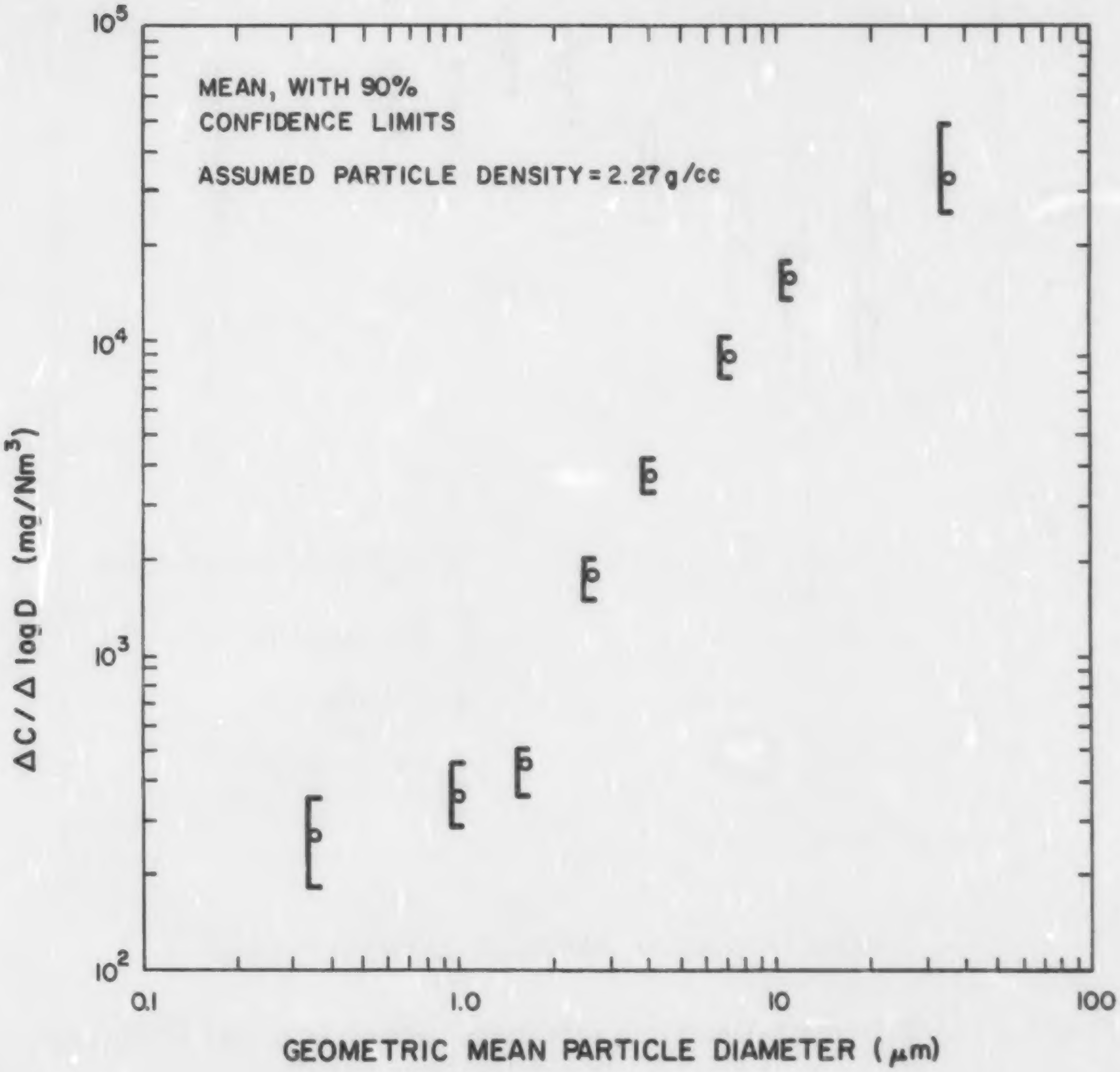


Figure A-10. Mean differential particle size distribution at inlet to ESP, Montour Plant, December 10, 11, 16, 17, and 18, 1975.

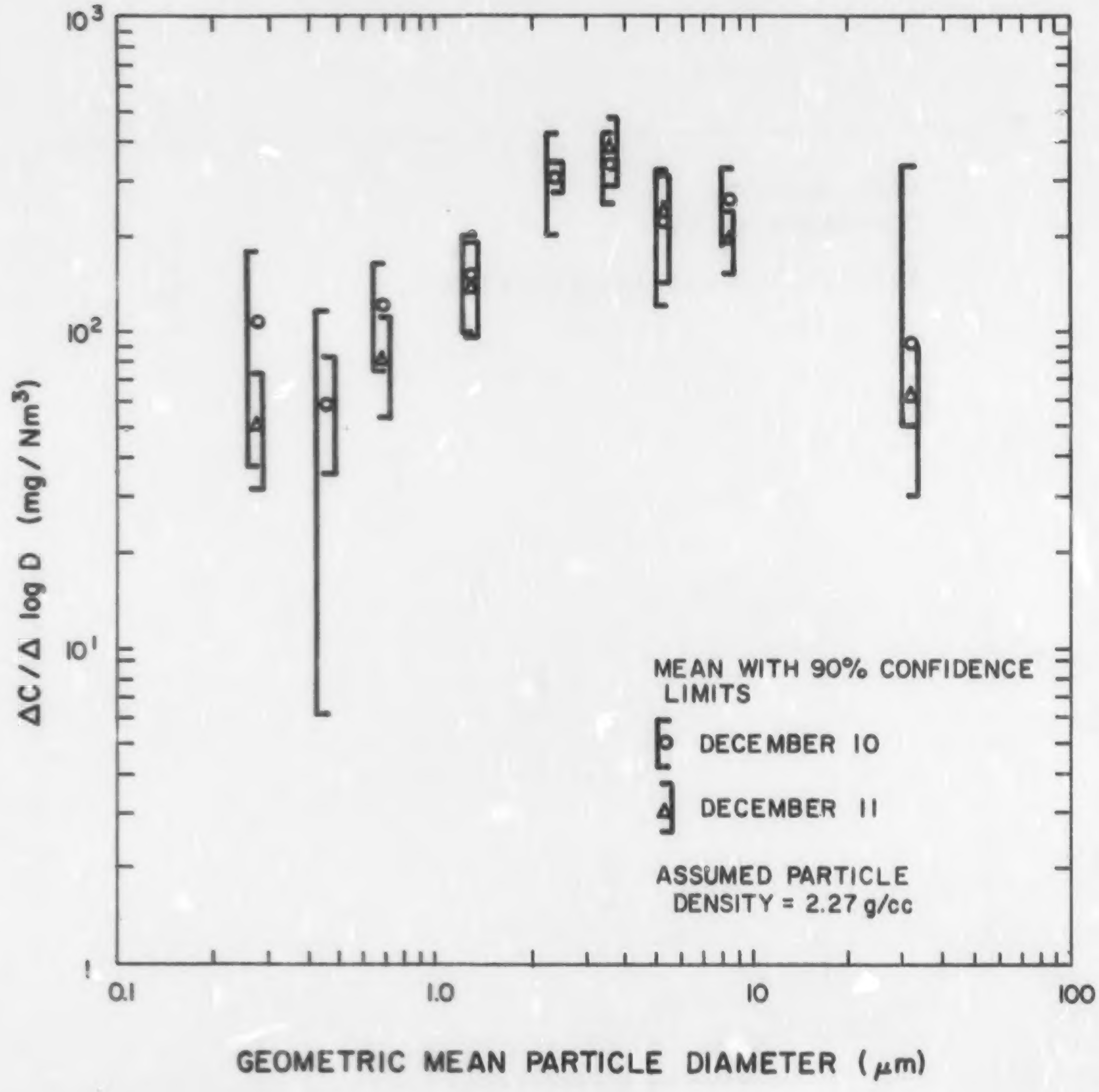


Figure A-11. Differential particle size distributions at outlet of ESP, Montour Plant, December 10 and 11, 1975.

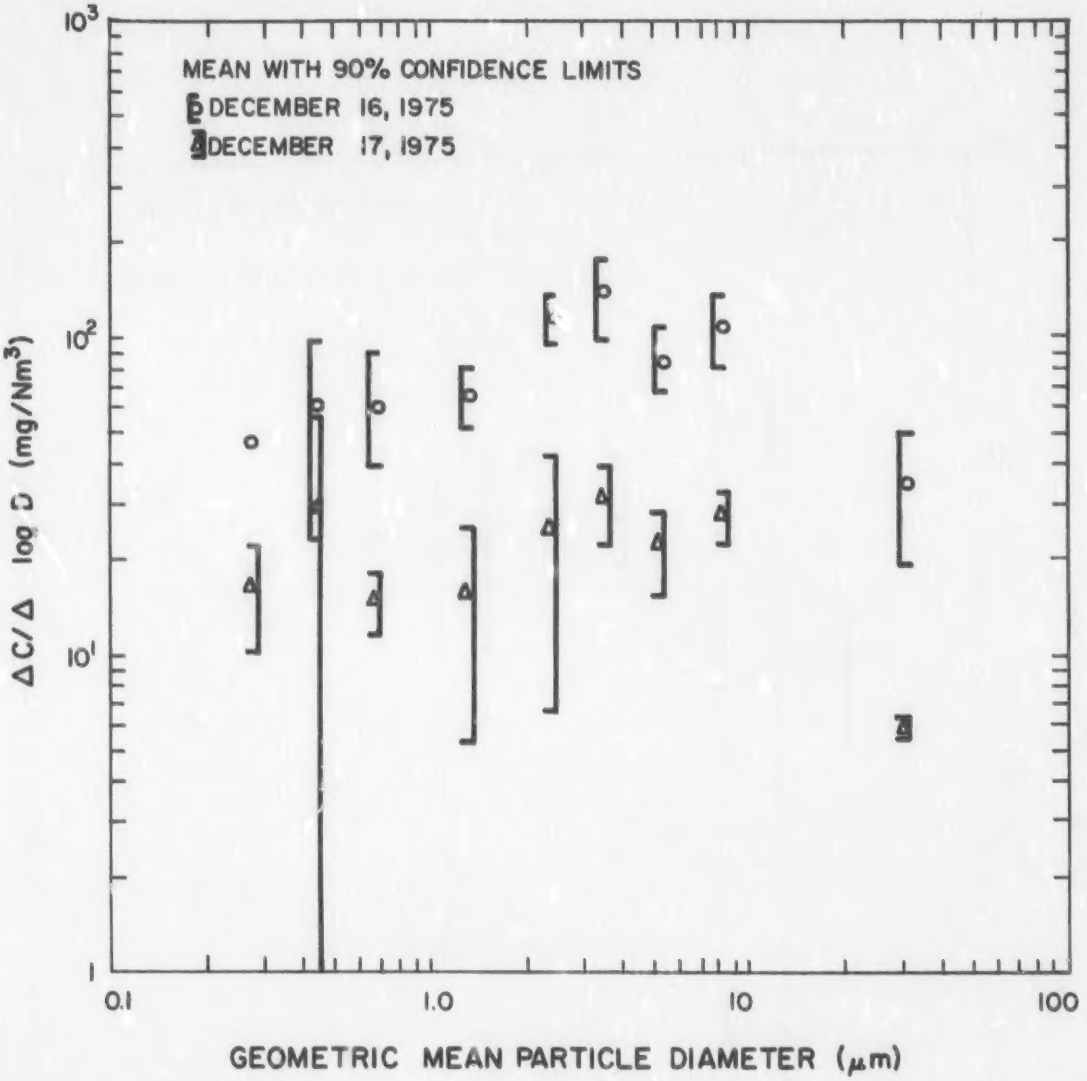


Figure A-12. Differential particle size distributions at outlet of ESP, Montour, December 16 and 17, 1975.

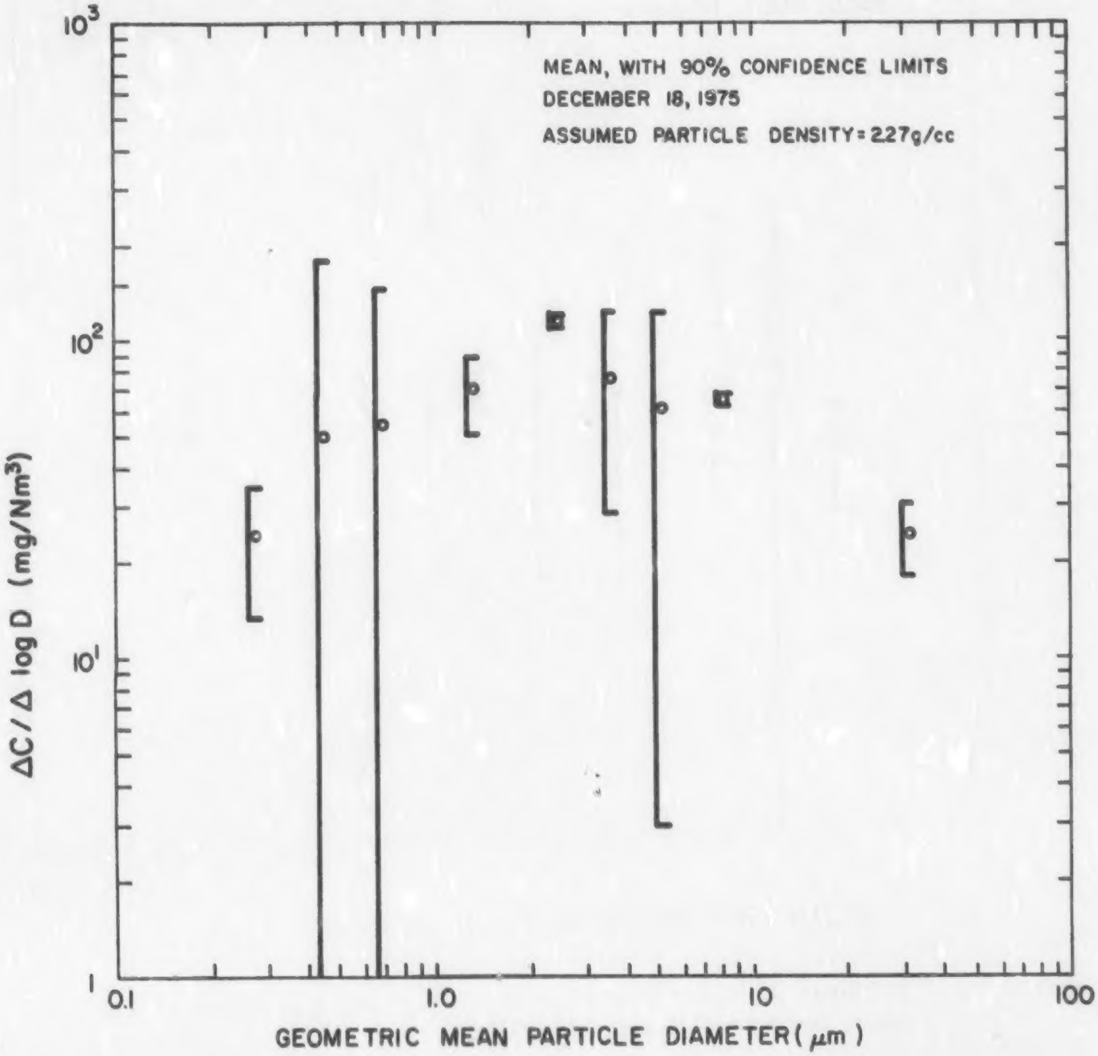


Figure A-13. Differential particle size distributions at outlet of ESP, Montour Plant, December 18, 1975.

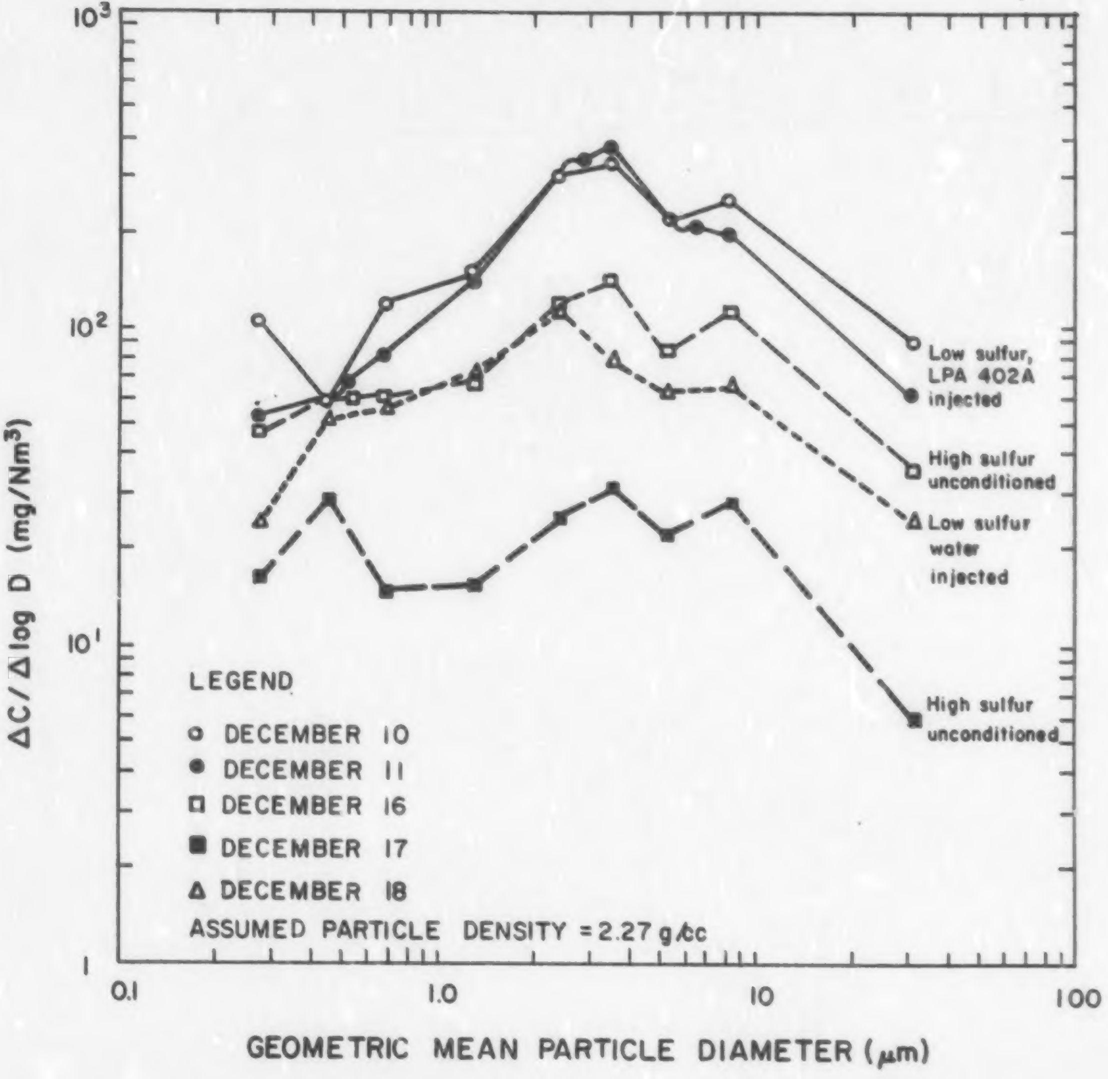


Figure A-14. Differential particle size distributions at outlet of ESP, Montour, December 10, 11, 16, 17, and 18, 1975.

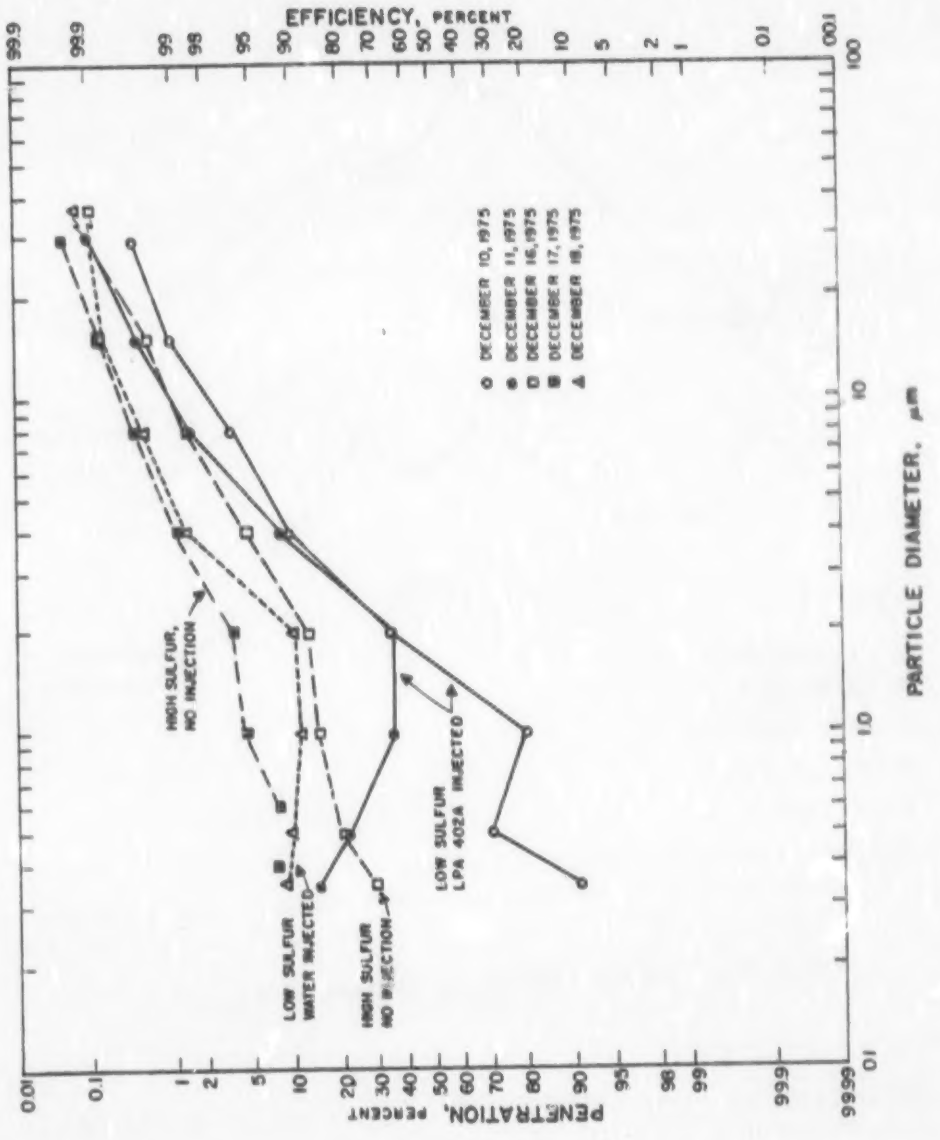


Figure A-15. Fractional removal efficiency of Montour ESP.

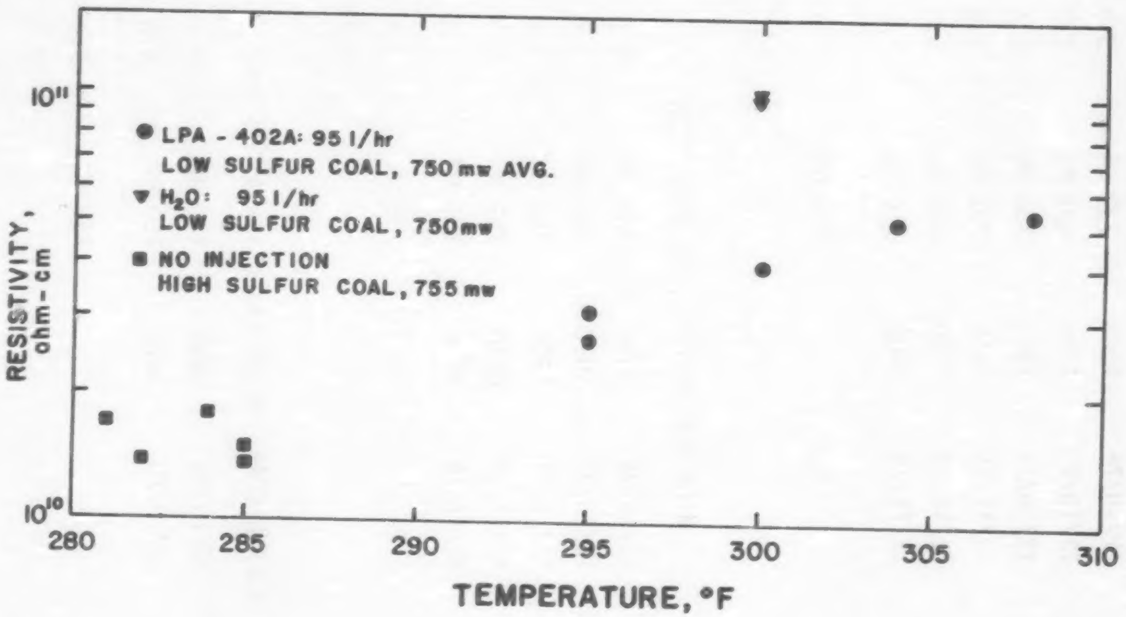


Figure A-16. Flyash resistivity measurements, Montour Power Plant.

TABLE A-8. FLYASH RESISTIVITY

Test	Temp, °F	DATE	TIME	CONDITION	RESISTIVITY Ω-cm
LOW SULFUR COAL, LPA 402A INJECTION AT 95 l/hr					
1A	308	12/10/75	1000	732 MW	5.3×10^{10}
1B	300	12/10/75	1200	635 MW	4.0×10^{10}
1C	304	12/10/75	1430	730 MW	5.1×10^{10}
2A	300	12/11/75	0915	735 MW	4.0×10^{10}
2B	295	12/11/75	1110	680 MW	3.1×10^{10}
2C	295	12/11/75	1400	710 MW	2.7×10^{10}
				703 MW	$4.0 \times 10^{10} = \overline{X}$
					$1.05 \times 10^{10} = \sigma$
					26% = CV
HIGH SULFUR COAL, NO INJECTION					
3A	284	12/16/75	0830	755 MW	1.8×10^{10}
3B	282	12/16/75	1030	755 MW	1.4×10^{10}
3C	285	12/16/75	1300	755 MW	1.5×10^{10}
4A	281	12/17/75	0830	755 MW	1.7×10^{10}
4B	285	12/17/75	1600	755 MW	1.4×10^{10}
				755 MW	$1.5 \times 10^{10} = \overline{X}$
					$0.18 \times 10^{10} = \sigma$
					12% = CV
LOW SULFUR COAL, WATER INJECTION AT 95 l/hr					
5A	300	12/18/75	1500	750 MW	10×10^{10}
5B	300	12/19/75	1645	750 MW	9.8×10^{10}
				750 MW	$9.9 \times 10^{10} = \overline{X}$
					$0.14 \times 10^{10} = \sigma$
					1.4% = CV

$\overline{X}$ = Mean

σ = Standard Deviation

CV = Coefficient of Variation = $(\sigma \times 100\%)/\overline{X}$

402A injection lowered the low sulfur coal flyash resistivity by about 60 percent as compared to water injection.

Lowered flyash resistivity leads to expectations of improved precipitator performance, but this was not the case at Montour. An empirical explanation may be that the low sulfur, unconditioned ash collection data was influenced by the high sulfur coal run the day before. This "inertia" effect has been observed at other test sites. Some indication of its presence may be found in the significant difference between the collection efficiencies on the two days of high sulfur coal. Boiler variables were fairly constant, as was flyash resistivity, but collection improved on the second day.

3.6 BOILER OPERATION PARAMETERS

The available information on boiler operation during the Montour test is presented in Table A-9. Significant load variations occurred while testing was going on only at 1200-1400 on December 10. The measurements which were in progress at about this time were outlet sulfur oxides, outlet ammonia, organics, particulates, and flyash resistivity.

TABLE A-9. BOILER OPERATION PARAMETERS, MONTOUR TEST

		0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	2400
12/10/75													
LOAD	(MW)	749	752	750	722	720	642	577	725	734	737	706	647
Gas Outlet Temp (°F)	A	298	299	299	300	295	289	285	287	287	284	283	276
	B	286	290	291	287	294	290	275	291	292	295	292	280
Oxygen Conc. (%)		5.3	5.2	5.2	5.2	5.2	5.1	5.7	5.1	5.2	5.1	5.3	5.1
12/11/75													
LOAD	(MW)	468	471	710	735	735	710	700	712	748	751	737	751
Gas Outlet Temp (°F)	A	259	257	277	286	287	284	283	289	291	292	290	289
	B	248	250	278	288	290	290	290	289	292	293	292	288
Oxygen Conc. (%)		5.2	5.5	5.0	5.2	5.1	5.1	4.9	5.0	5.2	5.2	5.0	5.0
12/16/75													
LOAD	(MW)	488	489	570	746	742	748	745	756	755	755	756	745
Gas Outlet Temp (°F)	A	268	264	272	294	297	300	300	298	299	289	290	289
	B	251	259	270	292	294	298	299	290	288	286	286	286
Oxygen Conc. (%)		5.1	5.2	5.4	5.0	5.4	5.3	5.6	5.6	5.4	5.5	5.5	5.1
12/17/75													
LOAD	(MW)	756	---	---	728	735	739	729	724	759	758	758	754
Gas Outlet Temp (°F)	A	289	288	271	269	276	278	279	286	301	298	297	295
	B	285	285	268	272	276	278	280	281	289	290	289	289
Oxygen Conc. (%)		5.1	5.2	5.2	5.2	5.4	5.1	5.3	5.3	5.1	5.0	5.0	5.0
12/18/75													
LOAD	(MW)	750	746	750	746	745	749	743	746	737	740	760	750
Gas Outlet Temp (°F)	A	292	294	292	290	289	291	288	288	284	285	286	285
	B	288	288	289	288	288	286	292	290	290	290	290	290
Oxygen Conc. (%)		5.0	5.0	5.3	5.3	5.2	5.1	5.2	5.1	5.2	5.0	5.0	5.0

SECTION A-4

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Battelle
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Columbus, Ohio 43201
Telephone (614) 424-6424
Telex 24-5454

APPENDIX A-A

April 15, 1976

Dr. Larry D. Johnson
Process Measurement Branch
Industrial Energy Research Laboratory
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Dear Larry:

Analysis of Monteurville Power Plant Effluent
(Contract No. 68-02-1409, Task 42)

Five organic vapor samples of Monteurville power plant effluent were collected using Battelle Adsorbent Samplers. No filters or probe rinses were provided. The sample description and assigned sample numbers are given below

Sample	BCL Sample Number
#1 Monteurville power plant effluent	J1
#2 Monteurville power plant effluent	J2
#3 Monteurville power plant effluent	J3
#4 Monteurville power plant effluent	J4
(Unlabelled sampler, contained blue liquid)	BW1

Level I Analyses

Level I analyses on the five samples were carried out according to the methods defined in 'Technical Manual on Measurement of Organic Materials in Process Streams' prepared for EPA by BCL. The weight of material in each fraction is given in the following table.

Sample	Fraction Weight (g)							
	1	2	3	4	5	6	7	8
J1	0.0041	0.0011	0.00054	0.0068	0.00082	0.0057	0.0014	0.00006
J2	0.0024	0.00044	0.00054	0.0091	0.00084	0.0065	0.00009	0.00003
J3	0.00023	0.00018	0.00023	0.0060	0.00018	0.00048	0.00004	0.00008
J4	0.00018	0.000077	0.00013	0.0039	0.00021	0.00027	0.00003	0.00001
BW1	0.0014	0.0038	0.00047	0.0010	0.00047	0.0077	0.00001	0.000005

Infrared analysis of the 40 individual fractions was carried out by Fourier Transform infrared spectroscopy (FTIR); the results are shown in the attached Table of Level I analytical data. The original FTIR spectra will be supplied upon request.

Nitrosamine Analysis

This Task specifically requested quantitative Level II analysis for nitrosamines in the collected samples. Following discussion with EPA personnel, it was agreed that the nitrosamine of concern was diethylnitrosamine, in view of the amine additives used in this power plant.

Analysis was carried out by GC-MS specific ion current integration, in a similar manner to that successfully employed for POM analyses in these laboratories. Aniline was selected as an appropriate internal standard, in view of its similar volatility to the nitrosamine (boiling points 184 and 177 C, respectively). Gas chromatographic separation of diethylnitrosamine and this internal standard were satisfactorily achieved on a 6-foot Silar 10CP column. Mass spectrometric analysis was accomplished by methane chemical ionization, using a Finnigan 3200 quadrupole mass spectrometer with an interfaced PDP8 computer for data handling.

The analytical technique is illustrated by the analysis of a standard mixture containing 1000 ng each of the nitrosamine and the internal standard, as shown in the attached reconstructed gas chromatogram (RGC). In this attached RGC, the black trace depicts the total ion current for the GC-MS analysis of a mixture of nitrosamine and standard. The red trace is an ion overlay for the ion m/e = 103 (nitrosamine) and the green trace is the ion overlay for the ion m/e = 94 (standard). The two attached mass spectra (22-18) and (90-83) are the methane chemical ionization mass spectra for diethylnitrosamine and aniline, respectively; the ions groups at m/e = 101, 102, 103, 104 and 92, 93, 94, 95 were used for the quantitative analysis, as described in the 'Technical Manual for Measurement of Organic Materials in Process Streams' (prepared for EPA by BCL). It is clearly evident that highly selective nitrosamine analysis is provided by this technique.

Prior to actual sample analysis, extensive studies were carried out to determine the optimum method for concentrating the pentane extracts of the Adsorbent Samplers, and also to determine the typical nitrosamine recoveries and quantitation calibration factor. The entire pentane extract of each sampler (about 120 ml) was subsequently concentrated by Kuderna-Danish evaporation to about 100 µl; the average nitrosamine recoveries were previously estimated to be greater than 80% by this technique. Calibration factors for quantitation (the ratio of specific ion current response for nitrosamine and standard) determined over the 1000 to 10,000 ng range, showed no significant variation, and thus, a mean value was chosen for the subsequent analysis.

The detection limit for diethylnitrosamine was shown to lie between 1 and 10 ng, by the analytical procedure described above; thus a reasonable detection limit of 5 ng was assumed.

Quantitative analysis of the five samples J1, J2, J3, J4, and BW1 failed to detect the presence of diethylnitrosamine in any sample. Thus we must assume that any diethylnitrosamine present was at levels lower than 5 ng in each sample. This laboratory was not supplied with details relating to the volume of stack gas sampled, but assuming a usual volume of 30 cu ft for the Battelle Adsorbent Samplers, this means that the upper limit for diethylnitrosamine content of the Monteurville power plant stack gas effluent was 5 parts per trillion (ppt).

Conclusion to Level II Nitrosamine Analysis

This program has clearly demonstrated the utility of the BCL-developed ion current integration techniques for the analysis of hazardous species such as nitrosamines in combustion effluents. In this instance diethylnitrosamine was not detected, but its upper limit in combustion effluent was reasonably estimated to be 5 ppt. Use of the developing EPA SASS train would lower this detection limit to about 0.2 ppt, on account of the larger gas volume which may be sampled by this system.

If you have any comments or questions with regard to the above results, please do not hesitate to contact me at Extension 1158, or Paul Strup at Extension 1710.

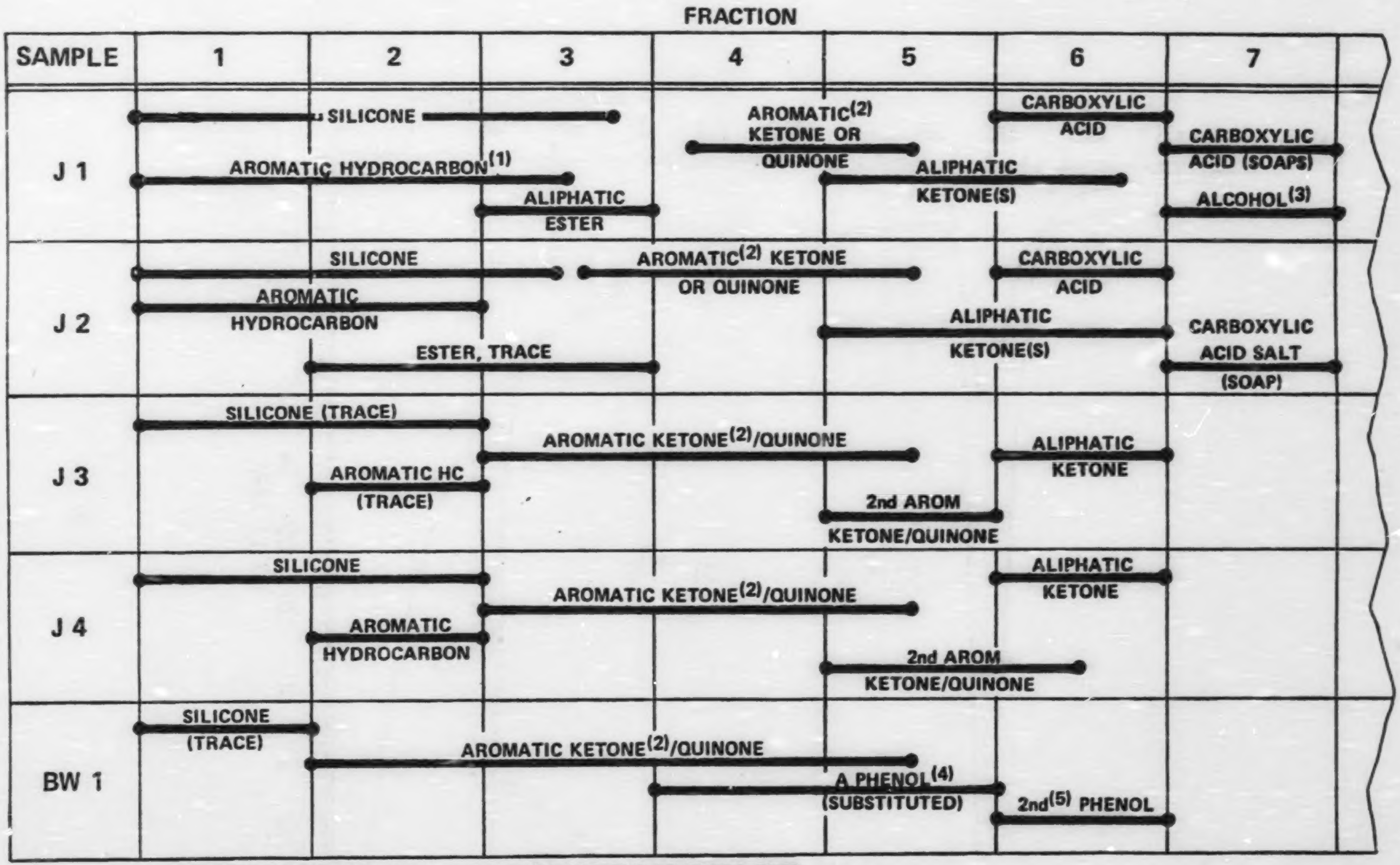
Sincere regards,

Peter

Peter W. Jones
Associate Manager
Organic and Structural
Chemistry Section

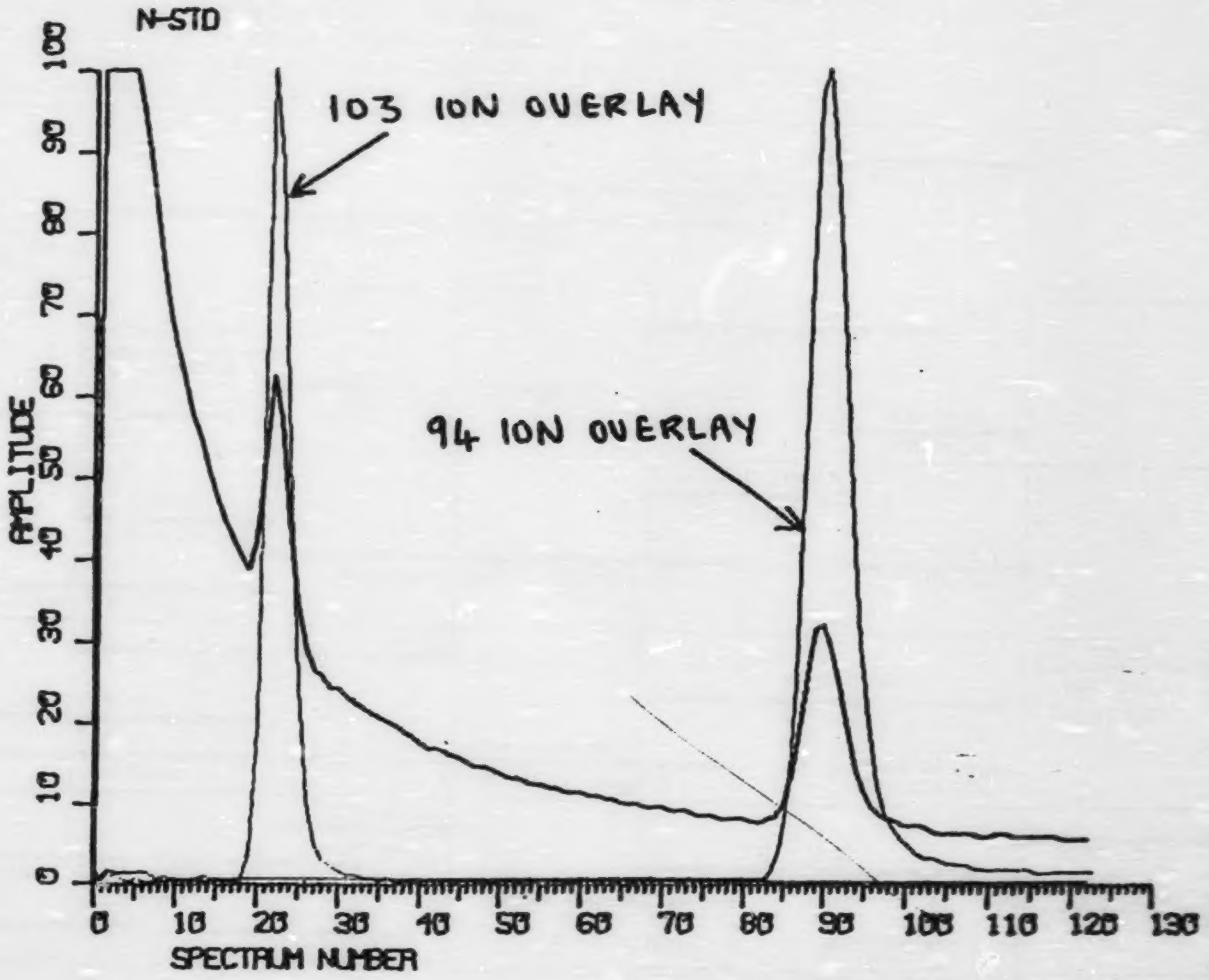
PWJ:pb

Enclosures

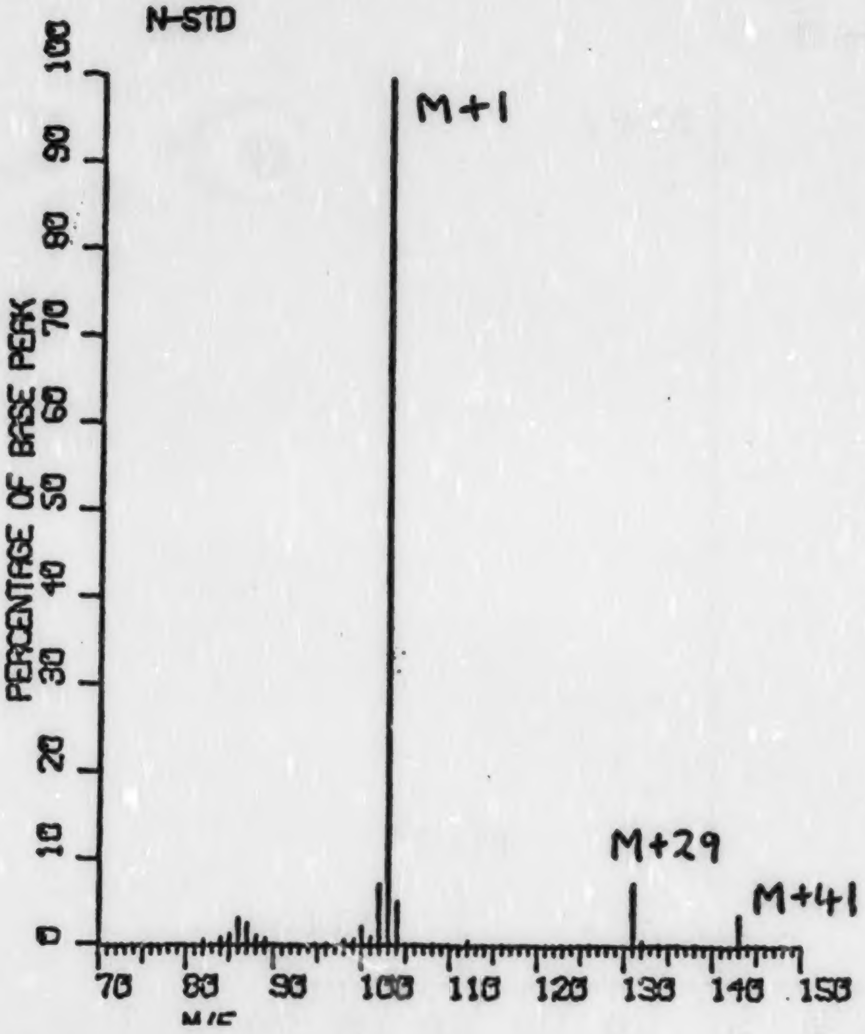

FRACTION
SAMPLE
1
2
3
4
5
6
7
J 1
SILICONE
AROMATIC HYDROCARBON(1)
ALIPHATIC ESTER
AROMATIC(2) KETONE OR QUINONE
ALIPHATIC KETONE(S)
CARBOXYLIC ACID
CARBOXYLIC ACID (SOAPS)
ALCOHOL(3)
J 2
SILICONE
AROMATIC HYDROCARBON
ESTER, TRACE
AROMATIC(2) KETONE OR QUINONE
ALIPHATIC KETONE(S)
CARBOXYLIC ACID
CARBOXYLIC ACID SALT (SOAP)
J 3
SILICONE (TRACE)
AROMATIC HC (TRACE)
AROMATIC KETONE(2)/QUINONE
2nd AROM KETONE/QUINONE
ALIPHATIC KETONE
J 4
SILICONE
AROMATIC HYDROCARBON
AROMATIC KETONE(2)/QUINONE
2nd AROM KETONE/QUINONE
ALIPHATIC KETONE
BW 1
SILICONE (TRACE)
AROMATIC KETONE(2)/QUINONE
A PHENOL(4) (SUBSTITUTED)
2nd(5) PHENOL

(1) AROMATIC HYDROCARBON, PROBABLY MULTIPLE OR FUSED RING
(2) SAME AROMATIC KETONE/QUINONE RUNS THROUGH ALL OF SERIES OF 5 SAMPLES
(3) ALIPHATIC ALCOHOL, POLYALCOHOL OR ALKANOL AMINE
(4) A PHENOLIC COMPOUND, PROBABLY PHENYL SUBSTITUTED
(5) PROBABLY A SECOND PHENOL, HIGHLY SUBSTITUTED, POSSIBLY POLYHYDROXY COMPOUND

LEVEL I ORGANIC ANALYSIS OF MONTEURVILLE POWER PLANT EFFLUENT
(CONTRACT 68-02-1409, TASK 42)


N-STD
103 ION OVERLAY
94 ION OVERLAY
AMPLITUDE
0
10
20
30
40
50
60
70
80
90
100
SPECTRUM NUMBER
0
10
20
30
40
50
60
70
80
90
100
110
120
130

SPECTRUM 22 - 18 DIETHYLNITROSAMINE



SPECTRUM 90 - 83 ANILINE (I.N.T. STD.)

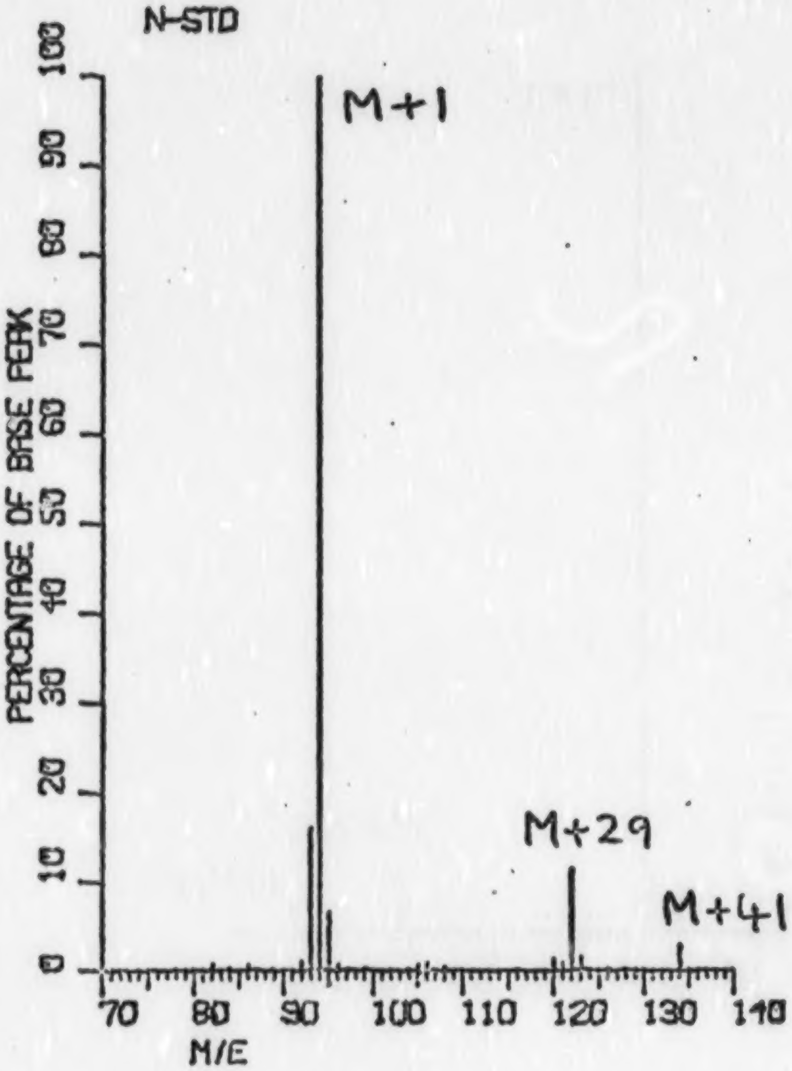


TABLE A-A-1. DIGEST OF DATA SHEETS FROM TENAX ORGANIC RUNS. MONTOUR STEAM POWER PLANT, DANVILLE, PA.

Run Number Field	Run Number Battelle	Date	Time	Orifice ΔP ("Hg)	Pump ΔP ("Hg)	Stack Temp. (°F)	Heater Box T. (°F)	Avg. Meter Temp. (°F)	Sample Volume (liters/scf)	Condenser Number
1	J1	12/10/75	1430-1645	1.25	7.5	240	--	94	1511.7/53.4	1
2	J2	12/11/75	0940-1220	1.25	7.5	230	--	93	1491.6/52.7	20
3	J3	12/16/75	1000-1222	1.25	7.8	260	250	71	1555.2/54.9	19
4	J4	12/16/75	1420-1635	1.25	10.0	260	250-300	80	1338.6/47.3	18
5	BW1	12/18/75	1515-1730	1.25	10.0	240	250-300	75	1389.4/49.1	15

NOTES:

Run #2

(1) Heater box went out for 15 minutes during run.
(2) Water condensing at outlet of Tenax condenser causing pressure drop.

Run #3

(1) Water condensation at outlet of condenser.

APPENDIX A-B

Southern Research Institute
2000 NINTH AVENUE SOUTH
BIRMINGHAM, ALABAMA 35205
TELEPHONE 205-323-6592

February 19, 1976

Mr. D. Bruce Harris
Project Officer
Environmental Protection Agency
Industrial Environmental Research
  Laboratory
Mail Stop MD-62
Research Triangle Park, NC 27711

Dear Bruce:

Here are the reduced data from Danville. We have included a description of procedures used to handle the blank weights, etc. If you need anything else, such as the computer printouts, please let me know.

Sincerely,

Wallace B. Smith
Wallace B. Smith
Head, Physics Section

WBS:mlm

Enclosures

Danville Tests and Impactor Data

Impactor data, both inlet and outlet, were handled according to the best professional skill of SRI personnel. Nevertheless, data taken on the following days' runs have been modified or deleted for the reasons given below. Also, particulate stage weights were compensated for background by subtracting stage weights obtained from the blank runs.

Outlet

11 December 75 - 1st run. Stage 8 deleted due to negative weight.

18 December 75 - 2nd run. Deleted completely due to extreme overloading of impactor.

Inlet

All stage 6 data were deleted due to the unreliability of the weights gathered (most lost weight).

9 December 75 (2 runs) and 10 December 75 (1st run) - deleted completely due to high flow rates and unreliability of numbers.

10 December 75 - 2nd run - Stage 5 deleted due to negative weight.

11 December 75 - 2nd run - Stages 1, 3, and filter deleted due to unreliability of weight or negative weight.

16 December 75 - 1st run - Stages 3, and 5 deleted due to negative weight.

16 December 75 - 2nd run - Stage 5 deleted due to negative weight.

16 December 75 - 3rd run - Stages 4, and 5 deleted due to negative weight.

Danville Tests-

18 December 75 - 2nd run - Stage 5 deleted due to negative weight.

18 December 75 - 5th run - Stage 5 deleted due to unreliability of number.

18 December 75 - 6th run - Deleted completely due to nozzle pointing downstream.

Table of Blank Data

Blank Runs

Date	12/10/75	12/11/75	12/16/75	12/17/75	12/18/75
SO	-0.42 mg	-1.89 mg	3.12 mg		0.45 mg
S1	-0.08	-1.05	0.55	4.19 mg*	0.43
S2	-0.57	-0.94	0.74	0.25	0.49
S3	-0.09	-0.77	0.68	0.16	0.38
S4	-0.30	-0.86	0.13	0.01	0.36
S5	-0.64	0.91	0.13	-0.10	0.33
S6	-0.55	-1.14	0.07	0.14	0.32
S7	-0.09	-0.65	0.32	-0.19	0.39
S8	-1.02	-0.36	0.28	0.06	0.70
SF				0.37	
			$\bar{x}=0.36$	$\bar{x}=0.12$ w/o negatives	$\bar{x}=0.43$

The blanks for 10 December and 11 December had negative weight gains because of severe sticking of the substrates. Thus, no modification of the particulate-gathering runs was made. Otherwise, Stages S1 thru S8 were averaged ($\bar{x}$ shown) and these were subtracted from particulate-gethering runs for that day. SO was subtracted from SF for each day. If subtraction produced zero or negative weight gains, then zero was entered.

*O-ring left out. Thus, S1 acted as a filter, and this run was treated as a blank with S1 weight ignored.

TABLE A-B-1. INLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLI -3	PPLI-4	PPLI-5	PPLI-6
Date	12/10/75	12/10/75	12/10/75	12/10/75
Amb. Press. ("Hg)	29.25	29.25	29.25	29.25
ΔP ("Hg)	0.6	0.2	0.9	0.2
Stack Temp (°F)	285	285	285	285
Sampling Time (min)	35	15	10	20
Flow Rate (acfm)	0.038	0.022	0.022	0.022
Impactor Ident.	---	164	157	---
Set Ident.	5N	4N	6N	7N
Start Time	0920	1100	1540	1620
Brink Impactor Stage Weights (mg)	[c]			
CYC	176.57	199.92	128.88	183.43
S0	9.84	12.38	7.42	15.17
S1	15.58	7.62	6.21	8.09
S2	6.86	4.85	3.92	3.08
S3	1.95	1.39	1.03	0.92
S4	1.00	0.71	0.46	0.33
S5	0.71	-0.07 [a]	0.07	0.24
S6 [b]	---	---	-0.16 [a]	---
SF	0.69	0.24	0.10	0.10

NOTES:

[a] Negative stage weights treated as zero weight.

[b] All stage 6 data deleted as unreliable. Most lost weight.

[c] Run deleted. High flow rate.

TABLE A-B-2. INLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLI-7	PPLI-8	PPLI-9	PPLI-10
Date	12/11/75	12/11/75	12/11/75	12/11/75
Amb. Press. ("Hg)	29.52	29.52	29.52	29.52
ΔP ("Hg)	0.2	0.9	0.2	0.2
Stack Temp. (°F)	285	285	285	285
Sampling Time (min)	10	10	10	10
Flow Rate (acfm)	0.022	0.022	0.022	0.022
Impactor Ident.	164	157	---	164
Set Ident.	8N	10N	9N	11N
Start Time	0950	1045	1345	1445
Brink Impactor Stage Weights (mg)				
CYC	146.29	305.54	205.68	182.41
S0	9.68	13.86	12.67	11.46
S1	10.71	7.41 [c]	13.66	14.25
S2	3.79	2.65	3.98	4.57
S3	1.06	- 0.80 [a]	1.83	1.81
S4	0.37	0.14	0.47	0.36
S5	0.18	0.17	0.25	0.14
S6 [b]	---	- 0.14 [a]	---	---
SF	0.21	- 0.28 [a]	0.43	0.40

NOTES:

a Negative stage weights treated as zero weight.

b All stage 6 data deleted as unreliable. Most lost weight.

c Deleted as unreliable weight.

TABLE A-B-3. INLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLI-11	PPLI-12	PPLI-13	PPLI-14	PPLI-15	PPLI-16
Date	12/16/75	12/16/75	12/16/75	12/16/75	12/16/75	12/16/75
Amb. Press. ("Hg)	29.52	29.52	29.52	29.52	29.52	29.52
ΔP ("Hg)	0.2	0.9	0.2	0.2	0.2	0.9
Stack Temp (°F)	285	285	285	285	285	285
Sampling Time (min)	10	10	10	10	10	10
Flow Rate (acfm)	0.022	0.022	0.022	0.022	0.022	0.022
Impactor Ident.	164	157	---	164	---	157
Set Ident.	12N	13N	14N	15N	16N	17N
Start Time	0920	1022	1001	1350	1440	1520
Brink Impactor Stage Weights (mg)						
CYC	57.0	109.3	67.5	84.6	73.0	86.0
S0	2.56	11.36	12.82	6.87	8.39	10.35
S1	2.24	9.94	7.71	7.47	8.63	7.21
S2	1.09	3.04	2.70	3.16	2.99	2.85
S3	-0.57[a]	0.34	0.67	1.14	1.11	1.10
S4	0.21	0.39	-0.08[a]	0.55	0.70	0.48
S5	-0.49[a]	-0.13[a]	0.00	0.13	0.41	0.21
S6[b]	---	-0.08[a]	---	---	---	0.95
SF	0.16	0.14	0.07	0.30	0.29	0.24

NOTES:

[a] Negative stage weights treated as zero weight

[b] All stage 6 data deleted as unreliable. Most lost weight.

TABLE A-B-4. INLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLI-17	PPLI-18	PPLI-19
Date	12/17/75	12/17/75	12/17/75
Amb. Press. ("Hg)	29.60	29.60	29.60
ΔP ("Hg)	0.9	0.2	0.2
Stack Temp (°F)	281	281	281
Sampling Time (min)	10	14	10
Flow Rate (acfm)	0.022	0.022	0.022
Impactor Ident.	157	---	164
Set Ident.	18N	19N	20N
Start Time	0941	1030	1355
Brink Impactor Stage Weights (mg)			
CYC	56.7	67.5	64.0
S0	5.97	11.01	5.04
S1	3.93	9.26	7.70
S2	2.18	3.64	2.87
S3	0.82	1.09	0.87
S4	0.44	0.34	0.69
S5	0.12	0.18	0.15
S6 [a]	0.07	---	---
SF	0.27	0.32	0.40

NOTES:

a All stage 6 data deleted as unreliable. Most lost weight.

TABLE A-B-5. INLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLI-20	PPLI-21	PPLI-22	PPLI-23	PPLI-24	PPLI-25
Date	12/18/75	12/18/75	12/18/75	12/18/75	12/18/75	12/18/75
Amb. Press. ("Hg)	29.40	29.40	29.40	29.40	29.40	29.40
ΔP ("Hg)	0.9	0.2	0.2	0.2	0.2	0.2
Stack Temp (°F)	290	290	290	290	290	290
Sampling Time (min)	10	10	10	10	10	10
Flow Rate (acfm)	0.022	0.022	0.022	0.022	0.022	0.022
Impactor Ident.	157	164	None	157	164	None
Set Ident.	21N	22N	23N	24N	25N	26N
Start Time	1230	1315	1400	1445	1530	1615
Brink Impactor Stage Weights (mg)						a
CYC	133.4	104.2	103.0	108.8	72.7	12.1[a]
S0	14.50	10.36	10.53	10.07	9.02	1.42
S1	12.55	7.75	10.32	15.28	13.26	0.90
S2	5.97	5.61	4.93	3.15	4.28	0.46
S3	1.85	8.89	1.65	1.62	1.32	0.08
S4	0.82	0.45	0.83	0.62	0.36	0.18
S5	0.30	0.00	0.25	0.42	0.05[c]	0.04
S6[b]	0.08	---	---	---	---	---
SF	0.36	0.45	0.23	0.64	1.32	0.15

NOTES:

[a] Nozzle turned downstream on this run. Run not used in calculations.

[b] All stage 6 data deleted as unreliable. Most lost weight.

[c] Deleted as unreliable weight.

TABLE A-B-6. OUTLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLO-1	PPLO-2	PPLO-3	PPLO-4	PPLO-5
Date	12/9/75	12/10/75	12/10/75	12/10/75	12/10/75
Amb. Press. ("Hg)	29.20	29.25	29.25	29.25	29.25
ΔP ("Hg)	0.324	0.324	0.324	0.324	0.324
Stack Temp (°F)	280	280	280	280	280
Sampling Time (min)	60	20	20	20	20
Flow Rate (acfm)	0.5	0.5	0.5	0.5	0.5
Impactor Ident.	507	522	507	506	128
Set Ident.	A-28	A-29	A-30	A-26	A-27
Start Time	1545	0935	1100	1323	1545
Andersen Impactor Stage Weights (mg)					
S1	9.27	20.72	17.57	-0.42	11.45
S2	2.62	7.53	7.85	-0.08	5.80
S3	3.11	8.59	10.82	-0.57	5.86
S4	3.19	10.67	9.61	-0.09	7.61
S5	4.31	11.71	11.19	-0.30	7.70
S6	6.25	9.80	10.69	-0.64	6.85
S7	3.57	6.00	5.07	-0.55	3.69
S8	2.00	2.05	0.53	-0.09	1.70
SF	2.84	8.40	3.44	-1.02	5.21
Σ	37.16	85.47	75.77		55.87
				BLANK[a] RUN	

NOTES:

[a] Negative weight blank was not used. Severe substrate sticking problems.

TABLE A-B-7. OUTLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLO-6	PPLO-7	PPLO-8	PPLO-9	PPLO-10
Date	12/11/75	12/11/75	12/11/75	12/11/75	12/11/75
Amb. Press. ("Hg)	29.52	29.52	29.52	29.52	29.52
ΔP ("Hg)	0.324	0.324	0.324	0.324	0.324
Stack Temp (°F)	280	280	280	280	280
Sampling Time (min)	20	20	20	20	20
Flow Rate (acfm)	0.5	0.5	0.5	0.5	0.5
Impactor Ident.	522	128	506	507	522
Set Ident.	A-24	A-25	A-23	A-40	A-41
Start Time	0930	1100	1310	1415	1530
Andersen Impactor Stage Weights (mg)					
S1	13.19	12.31	-1.05	4.22	14.35
S2	5.03	4.76	-0.94	5.04	7.01
S3	6.55	6.93	-0.77	8.63	12.94
S4	11.45	8.83	-0.86	8.63	13.36
S5	10.05	11.50	0.91	8.27	11.37
S6	6.42	8.52	-1.14	7.09	12.30
S7	7.02	4.45	-0.65	3.69	3.45
S8	- 0.31[a]	1.80	-0.36	1.25	1.15
SF	3.59	1.42	-1.89	3.15	3.19
Σ	58.30	60.52	b	50.97	79.12
				BLANK RUN	

NOTES:

a Negative stage weight treated as zero weight.

b Negative weight blank was not used. Severe substrate sticking problems.

TABLE A-B-8. OUTLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLO-11	PPLO-12	PPLO-13	PPLO-14	PPLO-15
Date	12/16/75	12/16/75	12/15/75	12/16/75	12/16/75
Amb. Press. ("Hg)	29.52	29.52	29.52	29.52	29.52
ΔP ("Hg)	0.324	0.324	0.324	0.324	0.324
Stack Temp (°F)	280	280	280	280	280
Sampling Time (min)	30	30	30	30	30
Flow Rate (acfm)	0.5	0.5	0.5	0.5	0.5
Impactor Ident.	522	128	507	506	522
Set Ident.	A-42	A-43	A-44	A-45	A-46
Start Time	0915	1045	1256	1410	1545
Andersen Impactor Stage Weights[a] (mg)					
S1	9.45 (9.09)	15.00 (14.64)	9.56 (9.20)	3.12[b]	6.17 (5.81)
S2	4.33 (3.97)	5.15 (4.79)	6.36 (6.00)	0.55	4.05 (3.69)
S3	4.40 (4.04)	5.57 (5.21)	6.81 (6.45)	0.74	4.82 (4.46)
S4	5.24 (4.88)	6.18 (5.82)	7.99 (7.63)	0.68	4.94 (4.58)
S5	5.26 (4.90)	6.85 (6.49)	7.17 (6.81)	0.13	5.65 (5.29)
S6	5.69 (5.33)	6.38 (6.02)	7.93 (7.57)	0.13	5.76 (5.40)
S7	4.67 (4.31)	5.22 (4.86)	3.43 (3.07)	0.07	2.87 (2.51)
S8	4.17 (3.81)	2.10 (1.74)	2.08 (1.72)	0.32	1.63 (1.27)
SF	2.90 (0.00)	3.62 (0.50)	7.00 (3.88)	0.28[c]	3.08 (0.00)
Σ	(40.33)	(50.07)	(43.13)	$\bar{X}$ = 0.36[d] σ = 0.26 BLANK RUN	(33.01)

NOTES:

a Weights in parentheses are actual weights reduced by mean gain of stages S1-S8 during blank runs. Stage SF weight reduced by weight on blank SF.

b Weight gain of stage S0, which was same as that of final stage (SF).

c Weight on stage S8 in blank run configuration.

d $\bar{X}$ represents mean; σ represents standard deviation.

TABLE A-B-9. OUTLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLO-16	PPLO-17	PPLO-18	PPLO-19
Date	12/17/75	12/17/75	12/17/75	12/17/75
Amb. Press. ("Hg)	29.60	29.60	29.60	29.60
ΔP ("Hg)	0.324	0.324	0.324	0.324
Stack Temp (°F)	280	280	280	280
Sampling Time (min)	30	30	30	30
Flow Rate (acfm)	0.5	0.5	0.5	0.5
Impactor Ident.	507	128	507	128
Set Ident.	A-47	A-48	A-49	A-50
Start Time	0900	1045	1250	1405
Andersen Impactor Stage Weights [a] (mg)				
S1	4.19[b]	1.74 (1.62)	1.81 (1.69)	1.68 (1.56)
S2	0.25	1.43 (1.31)	1.21 (1.09)	1.21 (1.09)
S3	0.16	1.48 (1.36)	1.13 (1.01)	1.60 (1.48)
S4	0.01	1.61 (1.49)	1.15 (1.03)	1.50 (1.38)
S5	-0.10	1.86 (1.74)	0.75 (0.63)	1.55 (1.43)
S6	0.14	1.72 (1.60)	0.87 (0.75)	1.95 (1.83)
S7	-0.19	1.02 (0.90)	1.15 (1.03)	0.90 (0.78)
S8	0.06	0.44 (0.32)	0.61 (0.49)	1.79 (1.67)
SF	0.37	1.59 (1.22)	2.04 (1.67)	1.45 (1.08)
Σ	$\overline{X} = 0.12$[c] $\sigma = 0.09$ BLANK RUN	(11.56)		

NOTES:

a Weights in parentheses are actual weights reduced by mean gain of stages S1-S8 during blank runs. Stage SF weight reduced by weight on blank SF.

b Neglected as spurious point. O-ring left out and S1 served as a filter.

c Mean without including negative weights.

TABLE A-B-10. OUTLET IMPACTOR DATA, PP&L, MONTOUR PLANT

Run Code	PPLO-20	PPLO-21	PPLO-22	PPLO-23
Date	12/18/75	12/18/75	12/18/75	12/18/75
Amb. Press. ("Hg)	29.40	29.40	29.40	29.40
ΔP ("Hg)	0.324	0.324	0.324	0.324
Stack Temp (°F)	280	280	280	280
Sampling Time (min)	20	40	20	30
Flow Rate (acfm)	0.5	0.5	0.5	0.5
Impactor Ident.	128	507	?	522
Set Ident.	A-51	A-52	A-53	A-54
Start Time	1232	1420	1545	1620
Andersen Impactor Stage Weights[a] (mg)		b		
S1	5.15 (4.72)	110.75 (110.32)	4.62 (4.19)	0.43
S2	2.21 (1.78)	49.07 (48.64)	2.24 (1.81)	0.49
S3	2.25 (1.82)	82.85 (82.42)	3.30 (2.87)	0.38
S4	2.25 (1.82)	59.96 (56.53)	2.89 (2.46)	0.36
S5	4.23 (3.80)	30.00 (29.57)	4.26 (3.83)	0.33
S6	5.00 (4.57)	18.07 (17.64)	4.42 (3.99)	0.32
S7	3.57 (3.14)	7.59 (7.16)	1.80 (1.37)	0.39
S8	2.33 (1.90)	1.53 (1.10)	0.88 (0.45)	0.70
SF	1.90 (1.45)	2.39 (1.94)	1.62 (1.17)	0.45
Σ	(25.00)	(355.32)	(22.14)	$\overline{X}$ = 0.43 σ = 0.12 BLANK RUN

NOTES:

[a] Weights in parentheses are actual weights reduced by mean gain of stages S1-S8 during blank runs. Stage SF weight reduced by weight on blank SF.

[b] Run deleted due to severe overloading of impactor.

APPENDIX B

TABLE B-1. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 10 December 1975 LOAD: 720 MW
TIME: 8:15 AM EXIT GAS TEMP: A-291°F; B-296°F EXCESS AIR: 5.3%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	310	125	60
5B/6B	280	120	24
5C/6C	280	130	6
5D/6D	290	135	10
7A/8A	290	120	96
7B/8B	290	120	30
7C/8C	270	75	36
7D/8D	280	115	42
1A/2A	270	90	36
1B/2B	290	85	36
1C/2C	275	90	60
1D/2D	300	130	42
3A/4A	320	115	66
3B/4B	300	100	60
3C/4C	290	75	36
3D/4D	300	150	12

TABLE B-2. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 11 December 1975 LOAD: 749 MW

TIME: 8:45 PM EXIT GAS TEMP: 2A-291°F; 2B-291°F EXCESS AIR: 5.2%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	280-310	105-135	120
5B/6B	270-280	110-120	96
5C/6C	270-280	95-130	60
5D/6D	280-290	95-135	48
7A/8A	280-290	100-125	120
7B/8B	290-300	110-115	60
7C/8C	270-280	10-100	72
7D/8D	270-290	75-110	96
1A/2A	270-280	95-105	60
1B/2B	280-290	70-100	60
1C/2C	230-270	0-150	120
1D/2D	290-300	100-150	96
3A/4A	300-320	100-130	120
3B/4B	290-320	75-125	144
3C/4C	300-310	50-125	96
3D/4D	290-310	125-150	48

TABLE B-3. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 11 December 1975 LOAD: 738 MW

TIME: 11 AM EXIT GAS TEMP: 288-291°F EXCESS AIR: 5.1%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	300	125	90
5B/6B	232	122	60
5C/6C	240	128	72
5D/6D	290	135	60
7A/8A	295	122	120
7B/8B	295	110	90
7C/8C	235	60	60
7D/8D	230	85	72
1A/2A	235	105	48
1B/2B	300	90	66
1C/2C	235	55	72
1D/2D	300	160	60
3A/4A	310	125	90
3B/4B	300	105	90
3C/4C	300	100	80
3D/4D	295	125	48

TABLE B-4. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 16 December 1975 LOAD: 751 MW

TIME: 5:11 PM EXIT GAS TEMP: A-301°F; B-288°F EXCESS AIR: 5.0%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	310-340	75-125	36
5B/6B	280-300	75-100	60
5C/6C	310	130	0
5D/6D	290-310	115-140	6
7A/8A	300-330	100-130	16
7B/8B	270-300	75-100	48
7C/8C	280-300	75-125	21
7D/8D	280-300	115-135	36
1A/2A	290-310	85-115	12
1B/2B	280-290	105-110	3
1C/2C	310-330	150-225	24
1D/2D	300-310	215-225	24
3A/4A	300-350	75-105	40
3B/4B	290-310	50-100	72
3C/4C	290-310	75-100	60
3D/4D	290-300	125-150	16

TABLE B-5. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 16 December 1975 LOAD: 747 MW

TIME: 7:15 PM EXIT GAS TEMP: A-289°F; B-286°F EXCESS AIR: 5.4%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	290-320	50-100	64
5B/6B	290-300	50-100	72
5C/6C	290-310	105-135	8
5D/6D	290-310	115-140	6
7A/8A	300-320	75-120	40
7B/8B	290-310	80-110	54
7C/8C	290-310	50-125	24
7D/8D	290-310	100-125	22
1A/2A	280-300	85-110	12
1B/2B	270-280	90-100	4
1C/2C	280-320	50-200	24
1D/2D	300-320	215-230	20
3A/4A	300-330	50-125	75
3B/4B	290-320	50-100	64
3C/4C	290-310	50-200	12
3D/4D	300-310	150-165	6

TABLE B-6. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 16 December 1975 LOAD: 747 MW

TIME: 11:35 PM EXIT GAS TEMP: A-289°F; B-285°F EXCESS AIR: 5.3%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	290-310	50-65	60
5B/6B	270-280	50-65	48
5C/6C	290-300	90-115	36
5D/6D	300-310	135-145	6
7A/8A	310-320	95-110	42
7B/8B	300-310	90-100	72
7C/8C	280-300	60-105	48
7D/8D	290-300	105-120	24
1A/2A	300-310	80-95	36
1B/2B	290-300	95-107	6
1C/2C	300-330	160-190	60
1D/2D	310-320	220-240	6
3A/4A	310-340	75-100	60
3B/4B	310-320	55-90	60
3C/4C	280-320	50-125	36
3D/4D	310-315	170-185	6

TABLE B-7. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 18 December 1975 LOAD: 746 MW

TIME: 12:30 AM EXIT GAS TEMP: A-295°F; B-289°F EXCESS AIR: 5.0%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	290-320	55-75	72
5B/6B	280-300	70-90	60
5C/6C	300-310	85-125	24
5D/6D	270-290	60-105	30
7A/8A	310-320	100-120	36
7B/8B	305-315	110-120	30
7C/8C	290-300	95-120	36
7D/8D	290-300	120-125	48
1A/2A	290-310	70-95	36
1B/2B	300-310	105-115	12
1C/2C	310-320	130-170	60
1D/2D	300-310	215-225	36
3A/4A	300-320	70-85	72
3B/4B	290-310	55-80	72
3C/4C	280-300	55-100	60
3D/4D	280-290	105-120	48

TABLE B-8. PRECIPITATOR VOLTAGE - CURRENT DATA

UNIT: Montour #2 DATE: 18 December 1975 LOAD: 754 MW
TIME: 4:40 PM EXIT GAS TEMP: A-286°F; B-290°F EXCESS AIR: 5.0%

Control #	Primary Voltage	Primary Current	Estimated Sparks Per Min.
5A/6A	250	55	60
5B/6B	280	85	72
5C/6C	290	105	24
5D/6D	295	125	12
7A/8A	280	95	66
7B/8B	290	90	78
7C/8C	250	50	30
7D/8D	280	120	30
1A/2A	220	85	20
1B/2B	280	100	12
1C/2C	285	90	48
1D/2D	300	200	60
3A/4A	280	100	72
3B/4B	260	50	72
3C/4C	280	50	72
3D/4D	300	115	20

APPENDIX C

TABLE C-1. VOLTAGE VS CURRENT DATA

DATE: 16 December 1975 LOCATION: Montour POWER SET: 1A/2A
TIME: 6:15 PM CONDITION: High Sulfur Coal - No Injection

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
85	280	23.8	0.371	38.54	14
75	275	20.6	0.329	37.6	12
50	250	12.5	0.22	33.84	8.2
25	222	5.6	0.105	31.96	3.9

TABLE C-2. VOLTAGE VS CURRENT DATA

DATE: 16 December 1975 LOCATION: Montour POWER SET: 1B/2B
TIME: Not Available CONDITION: High Sulfur Coal - No Injection

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
110	285	31.35	0.480	38.5	18
100	280	28.0	0.45	37.6	17
87.5	275	24.0	0.39	36.7	15
75	260	19.5	0.34	34.8	13
50	250	12.5	0.23	32.9	8.6
25	200	5.0	0.11	27.3	4.1

TABLE C-3. VOLTAGE VS CURRENT DATA

DATE: 16 December 1975 LOCATION: Montour POWER SET: 1C/2C
TIME: Not Available CONDITION: High Sulfur Coal - No Injection

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
225	250	56.25			
125	300	37.5			
100	285	28.5		58.0	
75	275	20.62	0.651	17.8	24.3
50	250	12.5		16.0	

TABLE C-4. VOLTAGE VS CURRENT DATA

DATE: 16 December 1975 LOCATION: Montour POWER SET: 1D/2D
TIME: Not Available CONDITION: High Sulfur Coal - No Injection

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
225	300	67.5	1.05	38.54	39.2
200	300	60.0	0.91	39.48	34.0
175	290	50.75	0.81	37.6	30.3
150	280	42.0	0.69	36.7	25.8
125	265	33.1	0.57	34.78	21.3
100	250	25.0	0.46	32.9	17.2
75	235	17.62	0.34	31.02	12.7
50	210	10.5	0.28	22.56	10.5

TABLE C-5. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1A/2A
TIME: 12:15 PM CONDITION: Low Sulfur + 95 l/hr LPA 402A + H_2O

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
165	280	46	0.87	32	32
85	270	23	0.36	37.6	13.5
70	260	18.2	0.30	35.7	11.3
60	250	15	0.257	34.8	9.6
45	240	10.8		33.8	7.1

TABLE C-6. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1B/2B
TIME: 12:00 N CONDITION: Low Sulfur Coal + 95 l/hr LPA 402A + H_2O

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
170	270-300	48.5	0.884	32.9	33.0
105	280	29.4	0.458	38.5	17.1
90	270	24.3	0.388	37.6	14.5
75	260	19.5	0.328	35.7	12.2
65	250	11.3	0.28	34.8	10.5
55	240	13.2	0.234	33.8	8.76
45	230	10.4	0.194	32.0	7.25

TABLE C-7. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1C/2C
TIME: 11:30 AM CONDITION: Low Sulfur + 95 l/hr LPA 402A + H_2O

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
240	290-300	70.8	1.33	32	49.6
130	280-290	37.1	0.577	38.5	21.6
125	280	35	0.559	37.6	20.9
80	270	21.6	0.363	35.7	13.6
75	260	19.5	0.336	34.8	12.6
60	250	15.0	0.374	32.9	10.2
45	240	10.8	0.203	32.0	7.57

TABLE C-8. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1D/2D
TIME: 11:00 AM CONDITION: Low Sulfur + 95 l/hr LPA 402A + H_2O

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
230	300	69	1.1	37.6	41.2
170	280	47.6	1.27	37.6	47.5
140	270	37.8	1.06	35.7	39.6
125	260	32.5	0.561	34.8	21.0
105	250	26.3	0.465	33.8	17.4
90	240	21.6	0.394	32.9	14.7
75	230	17.3	0.324	32	12.1
60	220	13.2	0.255	31	9.54
45	210	9.45	0.195	29.1	7.27

TABLE C-9. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1A/2A
TIME: 1:30 PM CONDITION: Low Sulfur Coal + H_2O

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary* Current Amps	Secondary Voltage kV	Current Density nA/cm^2
70	260-300		0.36	32.9	13
105	280		0.46	37.6	17
85	270		0.37	36.7	14
70	260		0.31	34.8	12
60	250		0.26	33.8	9.9
50	240		0.22	32.9	8.2

*Calculated Current. Assume 60% Power Conversion

TABLE C-10. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1B/2B
TIME: 1:45 PM CONDITION: Low Sulfur Coal + H_2O

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
70	260-300	47.6	0.37	32	33
60	270		0.26	37	9.8
60	260		0.26	36	9.7
50	250		0.21	35	8.0
30	220		0.13	30	4.9

TABLE C-11. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1C/2C
TIME: 2:00 PM CONDITION: Low Sulfur Coal + H_2O Injection

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
70	250-320	20	0.35	33.8	13
50	240	12		32.0	8.4
30	230		0.13	31.0	5.0
20	220		0.091	29.1	3.4

TABLE C-12. VOLTAGE VS CURRENT DATA

DATE: 18 December 1975 LOCATION: Montour POWER SET: 1D/2D
TIME: 2:15 PM CONDITION: Low Sulfur Coal + H_2O Injection

Primary Current Amps	Primary Voltage Volts	Primary Power kW	Secondary Current Amps	Secondary Voltage kV	Current Density nA/cm^2
225	280-300		1.1	35.7	41
125	260		0.56	34.8	21
100	250		0.44	33.8	16
80	240		0.36	32.0	13
70	230		0.31	31.0	12
60	220		0.26	30.1	9.7
50	210		0.21	30.1	7.8
20	200		0.084	28.2	3.1

APPENDIX D

SO_2 REMOVAL IN AN ELECTROSTATIC PRECIPITATOR

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At frequent intervals, the discussion of SO_2 removal by electrostatic precipitation arises. This technique will work in principle because of the low ionization potential of the SO_2 molecule, but the method is not feasible in terms of conventional electrostatic precipitators, as shown by the following analysis.

We will determine the amount of time required to remove the SO_2 from a flue gas with an SO_2 concentration of 2000 ppm with an electrostatic precipitator operating with an average current density (j) of 100×10^{-9} A/cm^2. The SO_2 concentration corresponds to plants burning coal with a sulfur content of about 3 percent and the current density is on the high side of the average for flyash precipitators.

The number of molecules of SO_2 per cubic centimeter of gas is determined for Avogadro's number and the gas concentration for SO_2. Avogadro's number is the number of molecules present in 22.4 liters of a gas at standard conditions.

$$N_o = 6.024 \times 10^{23} \text{ molecules/22.4 liters}$$
$$= 2.7 \times 10^{19} \text{ molecules/cm}^3$$

For an SO_2 concentration of 2000 ppm, the number of SO_2 molecules/cm^3 is:

$$N_{SO_2} = N_o \times 2 \times 10^{-3} = 5.4 \times 10^{16} \text{ molecules } SO_2/cm^3.$$

The number of electrons reaching a 1 cm^2 area of the plate per second is determined from the current density.

$$N_e = 100 \times 10^{-9} \frac{\text{amp}}{\text{cm}^2} \times \frac{1 \text{ coulomb/sec}}{1 \text{ amp}} \times \frac{1 \text{ electron}}{1.6 \times 10^{-19} \text{ coulombs}}$$

$$N_e = 6.25 \times 10^{11} \text{ electrons/sec}$$

If each electron is attached to an SO_2 molecule, then there will be 6.25×10^{11} SO_2 molecules transported to each square centimeter of collection electrode per second.

For a plate-to-corona-wire spacing of 10 cm, the number of SO_2 molecules contained within a 1 cm^2 area between the wire and plate is the product of the SO_2 concentration (N_{SO_2}) and the volume (10 cm^3) or N_{SO_2} within the 10 cm space = 5.4×10^{17} SO_2 molecules.

The time required to remove the SO_2 molecules at a rate of 6.25×10^{11} molecules per second is the ratio of the concentration to the rate.

$$\text{Time} = \frac{5.4 \times 10^{17} \text{ molecules}}{6.25 \times 10^{11} \text{ molecules/sec}}$$

$$\text{Time} = 8.65 \times 10^{5} \text{ seconds} = 240 \text{ hours}$$

Thus we see that a precipitator must retain the gas stream for a period of 240 hours to remove 2000 ppm of SO_2. If the gas velocity through the precipitator were 1.5 m/sec, the precipitator length required would be 366 m!

APPENDIX E

CALCULATION OF EFFICIENCY AS A FUNCTION OF PARTICLE DIAMETER

The particle collection efficiency as a function of particle diameter was calculated as follows:

1. An "eyeball" curve was drawn through the inlet and outlet $\Delta C/\Delta \log d$ data contained in Appendix A for each day of testing.
2. Points were picked from the "eyeball" curves for calculation of the penetration of particles of diameter d, Pt(d).
3. Pt(d) was calculated from:

$$Pt(d) = (\Delta C/\Delta \log d)_{outlet} \div (\Delta C/\Delta \log d)_{inlet}.$$

4. Pt(d) data were plotted and curves drawn through the points.

The 90 percent confidence limits of the penetration versus particle diameter curve were estimated as follows:

1. An "eyeball" curve was drawn through the +90 percent confidence limit and -90 percent confidence limit of the inlet and outlet $\Delta C/\Delta \log d$ data for each day's testing. These curves were drawn, as nearly as possible, parallel to the curves through the mean of the $\Delta C/\Delta \log d$ points.
2. Points were picked from these curves for calculation of +90 percent Pt(d) and -90 percent Pt(d).
3. +90 percent Pt(d) was calculated from:

$$+90\%\ Pt(d) = -90\%\ (\Delta C/\Delta \log d)_{outlet} \div +90\%\ (\Delta C/\Delta \log d)_{inlet}.$$

4. -90 percent Pt(d) was calculated from:

$$-90\%\ Pt(d) = +90\%\ (\Delta C/\Delta \log d)_{outlet} \div -90\%\ (\Delta C/\Delta \log d)_{inlet}.$$

The points used to calculate Pt(d), +90 percent Pt(d), and -90 percent Pt(d) for the December 16 test data are shown in Table E-1.

The Pt(d) curve with estimated ± 90 percent confidence limits is shown in Figure E-1.

It is recognized that this procedure lacks statistical rigor. However, it does provide useful results. Work is underway to develop more rigorous methods of performing the calculations. This procedure does take into account the different confidence intervals for the various stages of impactors. In general, the lower stages, corresponding to diameters less than 2 microns, have wider confidence limits than do the upper stages. Thus the penetration versus particle diameter curves have very wide confidence bands for diameters less than 2 microns.

TABLE E-1. PENETRATION CALCULATIONS FOR DECEMBER 16, 1975

	$\frac{\Delta C}{\Delta \log d}$			$\frac{\Delta C}{\Delta \log d}$			$\frac{\Delta C}{\Delta \log d}$		
d micron	inlet	outlet	Pt(d)	+90% inlet	-90% outlet	-90%Pt(d)	+90% inlet	-90% outlet	+90%Pt(d)
0.35	900	52	27.4	250	24	9.6	100	80	80
0.5	230	64	27.8	350	31	8.86	130	97	75
0.8	310	78	25	520	42	8.1	180	115	64
1.0	350	84	24	600	46	7.7	200	122	61
2.0	800	110	13.8	1300	60	4.62	500	160	32
4.0	2800	120	4.3	3800	65	1.71	1800	175	9.72
8.0	8800	95	1.07	12000	50	4.2	5500	140	2.55
10.0	13000	78	0.6	19000	47	0.25	7000	110	1.6
20.0	20000	50	0.25	27000	25	0.93	14000	75	0.54
30	25000	30	0.12	29000	20	0.07	21000	45	0.22

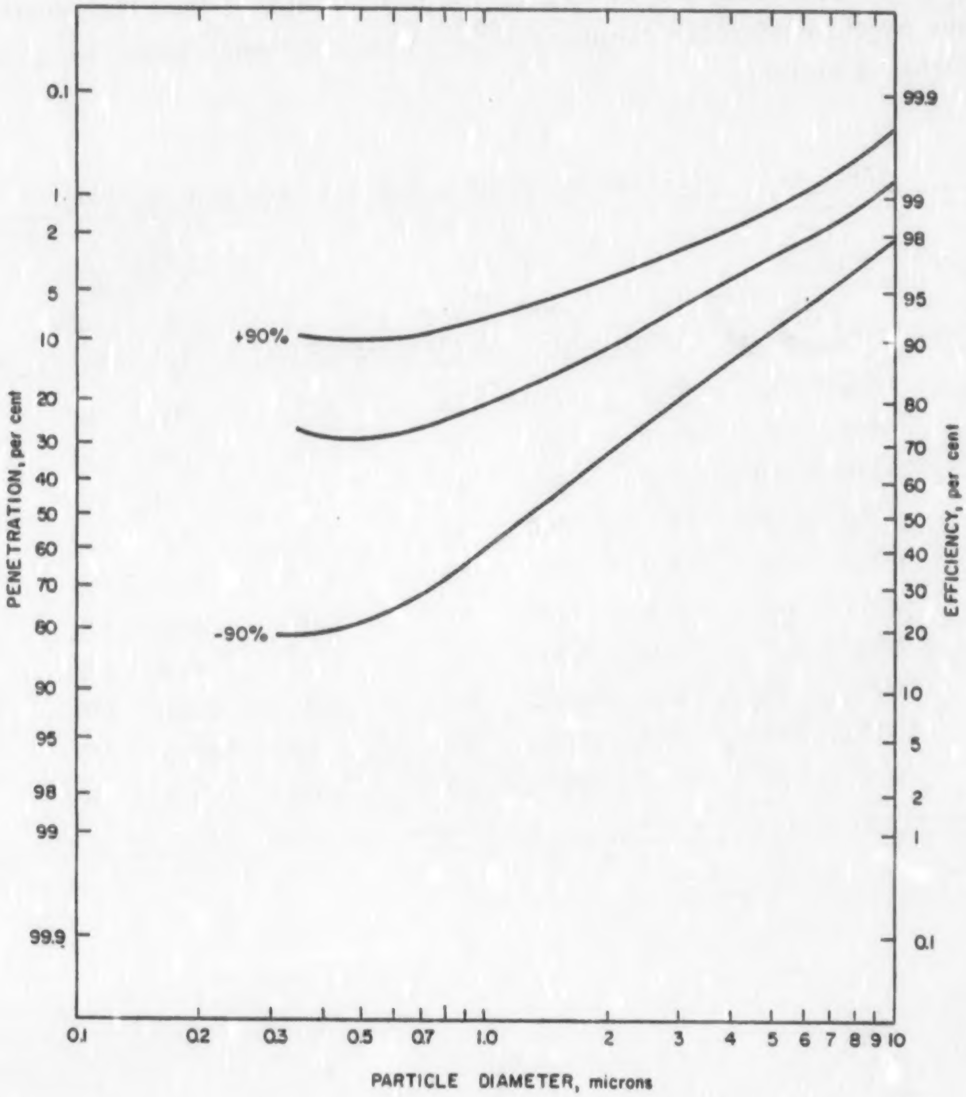

Figure E-1. Efficiency versus particle diameter for December 16 high sulfur coal.